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FEASIBILITY STUDY
for
LIGHT-MODULATED FILM VIEWING SYSTEM

FINAL REPORT

STATINTL

[redacted]

8 February 1965

DECLASS REVIEW by NIMA/DOD

[redacted]

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FEASIBILITY STUDY

FOR

LIGHT-MODULATED FILM VIEWING SYSTEM

FINAL REPORT

8 February 1965

Prepared by

[redacted]

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LIST OF ILLUSTRATIONS

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SECTION 1

INTRODUCTION

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A. SCOPE

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This report describes the work accomplished by [redacted] on a feasibility study of a Light-Modulated Film Viewing System. This study was initiated on July 15, 1964 and concluded on January 31, 1965. Section 2 of this report contains a brief summary of the results obtained on the program while Section 3 describes these results in detail. Section 4 describes a recommended follow-on program.

B. PROGRAM OBJECTIVE

The objective of this program was to prove the feasibility of a Light-Modulated Film Viewing System. This system is to be used for direct viewing and high magnification viewing through a microscope. The brightness of the backlight is to be modulated as a function of the transmissivity of the film and the spatial frequency so that the backlight intensity increases with a decrease in transmissivity and an increase in spatial frequency.

A further objective of this program was to construct a laboratory model and perform laboratory testing and evaluation in order to derive the necessary design data for the production of an operational prototype of the Light-Modulated Film Viewer.

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SECTION 2

SUMMARY AND CONCLUSIONS

This program has resulted in the development of techniques that will permit the implementation of a Light-Modulated Film Viewer in the form of a light table where the face of a cathode-ray tube forms the viewing surface. A thin (about 3-1/6-inch), transparent, plastic sheet, mounted above the table, forms the detector for closed-loop operation. The film is placed between the CRT faceplate and the detector. Since the detector need not be in intimate contact with the film, dodging can be performed while the film is moving. The dynamic range of this viewer is over 60 to 1 and will have a dodging resolution of about 2500 elements over the 9-inch by 9-inch area. In obtaining this dodging, the resolution of the film is not impaired since the film is viewed directly. Results obtained from a small breadboard built on this program indicate that this dodging resolution is quite adequate for normal viewing. STATINTL [redacted] feels that a viewer of this type will result in a considerable improvement at a reasonable cost over present viewers. In dodging, there appears to be an optimum dodging resolution which is considerably below the basic resolution of the imagery.

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A photograph illustrating the effectiveness of [redacted] breadboard Light-Modulated Film Viewer is contained in an envelope (Page 3). The size of the breadboard viewer is 1-5/8-inches square resulting in about 9 dodging elements in each direction. These photo-

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This envelope contains

a copy

of

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RESULTS OF [redacted] LIGHT-MODULATED

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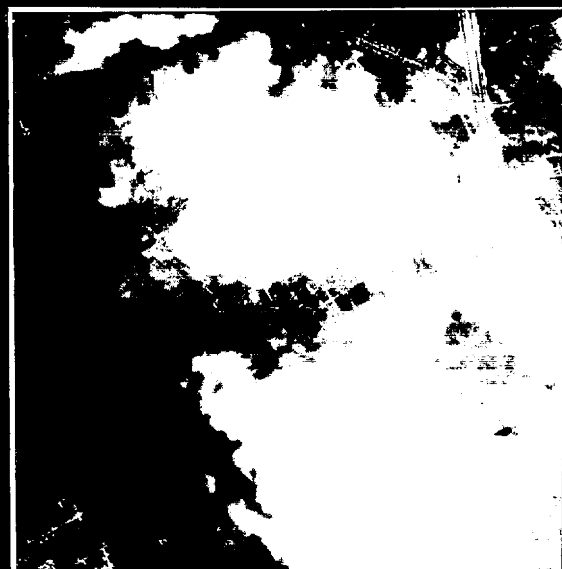
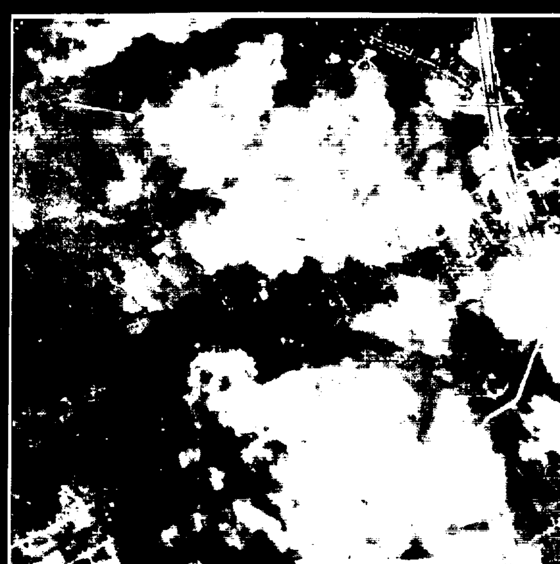


UNDODGED



DODGED

RESULTS OF [redacted] LIGHT-MODULATED FILM VIEWER BREADBOARD

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graphs were obtained using a conventional TV scan system. Since the dodging is essentially spot size limiting, a 9-inch by 9-inch system would have about the same dodging capability as shown in the photograph. [redacted] recommends that a full size (9-in by 9-in) viewer be built and evaluated by a panel of photointerpreters.

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[redacted]s approach to a Light-Modulated Film Viewer is to provide an intensity-modulated light table to permit the viewing of film either directly or with a microscope. This insures maximum viewing resolution limited only by the resolution of the imagery itself. Systems employing a projection system where the dodged film image is back-projected on a screen offers a simpler detection implementation; however, the film image resolution is degraded by the screen material and the projection optics. [redacted] approach to providing a modulated film viewer utilizes a single CRT which serves a dual function. As the CRT is scanned, a portion of the light transmitted through the film is detected and the resultant video signal is used to modulate the CRT spot. This CRT also serves as the backlight source.

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During the initial portion of the program, emphasis was placed on the development of a detector that would sample a portion of the light from the CRT that passed through the film. The initial approach utilized a dichroic mirror which reflected a portion of the light back through the film and onto a photomultiplier under the light table. This approach proved unfeasible because of the effec-

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tive squaring of the opacity of the film as light passed through the film twice. In addition, this approach did not permit an adequate diffuse backlight for viewing. These two effects reduced the signal-to-noise ratio of the detection system to an unacceptable level.

In view of these results, an effort was directed toward placing the sensor on the viewing side of the film. This effort resulted in a thin, large-area detector that consists of a sheet of plastic impregnated with a fluorescent material that is excited by the transmitted light. The radiation caused by the fluorescence is optically trapped within the plastic sheet and, through use of fiber optics, is transmitted to a photomultiplier. A detector, utilizing a Super Calcofluor impregnation, was developed and found to be sensitive to wavelengths up to 4200Å where it cuts off very sharply, and becomes transparent above this wavelength. Another detector utilizing Fluorescein was developed that proved very satisfactory for detecting the ultraviolet, as well as a portion of the visible spectrum. The development of these area detectors was a very significant achievement since it permitted the practical implementation of the light-table approach.

An effort was made to utilize a dual phosphor such as a P-16 and P-4 in combination, or a single phosphor that emitted in the ultraviolet with a very short persistence and also in the visible spectrum with longer persistence. With this approach, the detection is done with the short persistence portion and the backlighting for

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viewing with the longer persistence visible portion. The short persistence permits a high resolution detection system while the longer persistence is ideal for viewing. A CRT with a combination phosphor (P-16 and P-4) was purchased and evaluated. This tube did not yield adequate signal-to-noise ratio. Time did not permit a further investigation of combination phosphors, however, further work in this area is recommended. An attempt was made to use the very fast ultraviolet flash (0.05 μsec) of the P-15 for detection and the longer greenish-white for viewing. It was found that the ultraviolet to greenish-white radiation ratio as a function of grid current was not a constant which seriously limited the usable dynamic range of the system to about 10 to 1. Sensing the ultraviolet and a portion of the visible output of the P-15 yielded a much improved dynamic range (63 to 1). This sensing scheme limits the detection video bandwidth to 300 kc; however, the trade-off of resolution for increased dynamic range appears warranted.

The scanning spot must be of relatively high resolution for detection yet diffuse for viewing. A special fluorescent plate that satisfies these requirements was developed. This plate when excited by ultraviolet (from a P-15 or P-16 CRT) fluoresced in the green region yet passed a portion of the ultraviolet specularly and this transmitted portion could be used for detection. The conversion efficiency of this fluorescent plate was judged too low for practical application. The most practical solution to the backlight problem is to use the CRT face as the light table. A small spot can be

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obtained at the film plane by using a fiber optics faceplate; however, such faceplates are quite expensive and manufacturing difficulties limit their size to about 12 inches in diameter. A solid glass faceplate offers the most practical solution although the diffusion through the plate limits the dodging resolution. Tests have shown that a 1/4-inch faceplate results in an effective spot size on the film of 0.186 inches. This results in a dodging resolution of about 50 elements across a 9-inch viewing distance. This resolution is not adequate for the detection and dodging, however, this appears quite adequate for the dodging as a function of film transmissivity.

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In the recommended follow-on program described in Section 4, [redacted] proposes to fabricate a Light-Modulated Film Viewer for evaluation. In addition, advanced techniques studies are proposed in several areas in an effort to increase the effectiveness of a viewer of this type.

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SECTION 3

DETAILED DISCUSSION

A. INITIAL APPROACH

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Although the [redacted] proposal (GAP-2615) describes several approaches, the basic approach consisted of a CRT that served as the primary backlight and also as a flying spot scanner for the generation of video used in the detection of film characteristics. This detection circuitry was then used to control the intensity of the CRT in a closed-loop fashion. This approach is quite similar, in principle, to that used by [redacted] in contact printers and enlargers. The implementation, however, differed considerably. Since direct film viewing was given as a primary objective and since a detector such as a photomultiplier located above the film would interfere with the operator, the configuration shown in Figure 1 was used. In this approach, the video used for detection was obtained by scanning the film with the CRT. A portion of the light was reflected by the partial reflector located above the film and directed through the film a second time where it was detected by a photomultiplier located within the light table. This eliminated any detector above the film that might interfere with the operator.

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This basic approach was pursued through the study program. As in any feasibility study of this type, design modifications were

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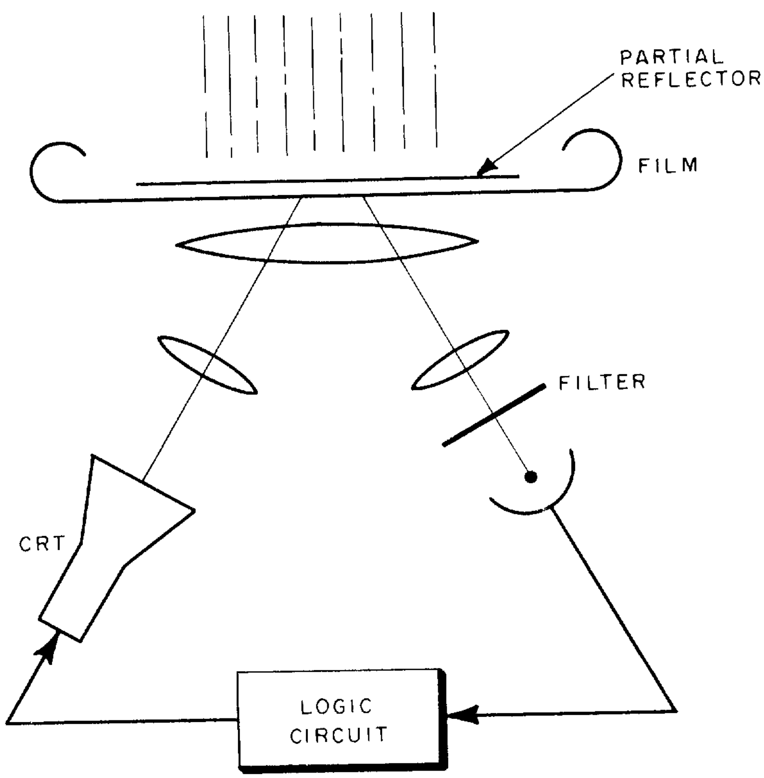

Figure 1. Initial Film Sensing Technique

made to circumvent the problem areas in an effort to arrive at an optimum system configuration. The problem areas and solutions to these problems are described in subsequent sections.

B. PROBLEM AREAS

During the initial portion of the study program, [redacted] STATINTL analyzed the initial approach described above and identified several problem areas. One problem area consisted of the type and physical location of the detector. In the initial approach, a partial reflector was used above the film which reflected a portion of the

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light back through the film where it was detected by a photo-multiplier. Since this light path requires high resolution, the reflector must be in close contact with the film - thus preventing operation with moving film. Secondly, with this implementation, the light is required to pass through the film twice - effectively squaring the opacity of the film. In addition, reflections off the film base and the field lens shown in Figure 1 creates considerable noise in the detection circuitry. In view of these problems, a study of other detection techniques was initiated - the results of which are described in Section 3-C.

A second problem area identified was that of the backlight. To have a high resolution optical system for detection of film characteristics, the backlight should be specular. However, from a viewing standpoint, the backlight should be diffused. These opposing requirements justified a backlight study - the results of which are presented in Section 3-D.

A third problem area concerns the loop response of the system. This involves the loop stability as well as the overall dodging resolution which is a function of CRT spot size, resolution of the optics, video bandwidth, etc. This problem was investigated and is presented in Section 3-E.

C. DETECTOR STUDIES

To sense the emulsion density distribution on the film, the system required a large area transparent detector having the following characteristics: (1) response to radiation at or below 4000Å,

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(2) be transparent, and (3) have a very fast response time (< .1 µsec). Also, the phosphor used in the detector should emit radiation peaked at 4400Å, compatible with the spectral response characteristics of the [redacted] No. 6199 photomultiplier. In addition, the detector should not interfere with the normal viewing of the film. Therefore, [redacted] effort was directed toward a detector that would take the form of a flat, thin sheet that could be mounted over the film.

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The investigation was concentrated in obtaining a suitable luminescent material for the detector which satisfied these requirements. The transparent properties and high optical trapping efficiency of the chemically deposited transparent phosphors warranted investigation into this area. The results of work accomplished in this area and reported in a paper, ("Transparent Phosphor Coatings" by F. J. Studer and D. A. Cusano, July, 1955, Journal of the Optical Society of America) indicated that the physical properties of the then known phosphors did not satisfy the absorption and emission requirements of the detector. The emission spectrum of transparent phosphors under ultraviolet excitation ranged from yellow to green. In addition, the efficiency of conversion for ultraviolet radiation is normally less than 10 percent of that of cathode ray excitation. It was also found that the persistence of most of these phosphors was too long and therefore incompatible with the resolution requirements of the system.

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Further study of the literature revealed that many

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fluorescent dyes satisfy the emission characteristics of the desired detector. The fact that these dyes are fluorescent materials defines the persistence as being less than .01 μsec. This characteristic is desirable since it will not limit the resolution of the system. A number of these dyes were obtained and tested. Of these, Fluorescein and Super Calcofluor appeared to best satisfy the system requirements.

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Super Calcofluor is a commercial dye marketed by the [redacted]

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[redacted] In the concentrations necessary in the detector, it is transparent and colorless. Super Calcofluor was found to fluoresce under excitation wavelengths up to 4200Å with an emission spectrum in the blue. This material is readily soluable in the solvents of most plastics, and therefore, permits ease of fabrication.

A detector composed of Plexiglas impregnated with the Calcofluor was fabricated and tested on the experimental breadboard. The detector was found to work satisfactorily when radiated with the P-15 phosphor. The characteristics of this detector make it desirable in that the cut-off excitation frequency is in the ultraviolet range (4200Å), making the detector relatively insensitive to ambient lighting. This detector proved ideal for a system that utilizes only ultraviolet for detection since it is sensitive to these wavelengths yet passes everything above 4200Å.

The closed-loop studies, discussed in Section 3-E, indicated

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a need for a detector sensitive to a portion of the visible spectrum. A Fluorescein impregnated detector was tested and found to operate better than the Calcofluor when detecting a portion of the visible spectrum. This detector is ideal when it was necessary to sense both the ultraviolet and a portion of the visible radiation as was required in the closed-loop studies.

Table 1 is a comparison of the characteristics of some of the phosphors studied in the investigation and the Fluorescein and Calcofluor dyes. Some of the phosphors exhibited the necessary emission characteristics but possessed a long decay time. In addition, some of these phosphors are excitable only by cathode-ray radiation as opposed to the ultraviolet excitation available in the proposed system. By these comparisons, Fluorescein and Calcofluor appear to be the most compatible with system requirements.

Consideration was also given in the investigation to the substrate used in the detector. The trapping efficiency of the detector is a function of the index of refraction of the substrate. The criterion for internal reflection is Brewster's angle Θ_B where:

$$\text{Sin } \Theta_B = \frac{1}{n}$$

and n is the index of refraction. For maximum trapping efficiency, Θ_B should be as small as possible, implying that the index of refraction of the substrate should be as large as possible. For

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TABLE 1

COMPARISON OF FLUORESCEIN AND CALCOFLUOR DYES TO PHOSPHORS

Material	Physical Characteristics	Fluorescence		Phosphorescence		Excitation	
		λ Max.	Decay Time	λ Max.	Decay Time	Cathode-Ray	3650Å
Fluorescein	Green	4800Å	$<$ 0.01 µsec	4800Å	-	-	-
Super Calcofluor	Trans-parent	4200Å	$<$ 0.01 µsec	-	-	-	Yes
Hexagonal ZnO (P-15)	Colorless	3910Å	0.05 µsec	5100Å	2.8 µsec	Yes	Yes
Rhombic $BaSO_4$	Colorless	ultra-violet	$\sim$ 1.0 µsec	violet	1.0 µsec	Yes	-
Cubic ZnS	Colorless	blue-violet	$<$ 1.0 µsec	-	-	-	-
Calcium-Magnesium Silicate (P-16)	White	-	-	3830Å	0.12 µsec	Yes	-
Esculin in Sugar	White	4430Å	-	5400Å	-	-	-
Anthacene	Colorless	violet	-	-	-	-	-
ZnS:P	trans-parent	-	-	-	-	green and blue	green
ZnS:As	trans-parent	-	-	-	-	yellow and blue	yellow

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Plexiglas having an index of 1.49, the Brewster angle θ_B is approximately 42^o. Assuming a uniform diffuse emission of radiation from the dye within the substrate, and assuming zero losses through the edges of the detector and at each successive internal reflection, 87 percent of the emitted radiation is trapped in the detector and 13 percent is transmitted through the faces of the detector. In practice, however, part of the radiation is lost through the edges before it can reach the photomultiplier tube. This loss is dependent upon position of the radiating point within the detector, resulting in a change in sensitivity of the detector across its face. However, a fiber optic array can be used to correct this situation and also minimize losses through the edges of the detector. One edge of the array will be connected along the edge of the detector with the other ends of the fibers connected to the face of the photomultiplier. This configuration would minimize the light lost through the edges of the detector and eliminate the sensitivity variation across the face of the detector.

D. BACKLIGHT STUDIES

Desired characteristics of the viewer backlight dictate two opposite characteristics, namely (1) the backlight should appear diffused to the observer to allow off-axis viewing of the imagery, and (2) since the backlight is used as a sensing element in the electronic dodging system, it should also appear specular to satisfy each of the two conditions.

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One implementation requires the film to be placed directly on the face of a cathode-ray tube. If the glass face of the CRT is thin or the illumination distribution of the spot is specular, the desired resolution of the system can be obtained. Generally speaking, however, neither of these conditions can be met. The thickness of the faceplate tends to increase the size of the spot as seen by the detector. A spot with a somewhat specular emission distribution, as found in transparent phosphors, generally lacks the necessary brightness levels required by the system.

However, the effective spot size can be reduced by utilizing a fiber optic faceplate on the CRT. In this type of CRT, the phosphor is deposited on the inner surface of the faceplate. The fibers effectively translate the emitted radiation of the phosphor to the outer surface of the plate, in effect creating a radiating point source on the outer face of the CRT. Placing the film on the faceplate puts this point source in contact with the film emulsion. The diffuse nature of the point source is of no consequence due to this direct physical contact of source and film emulsion. The limiting factor in sensing resolution of this system is the spot size of the CRT phosphor and the diameter of the individual fiber. Generally, the size of this fiber is usually a fraction of the diameter of the spot. The backlight will appear diffuse to the observer since the radiation produced by the phosphor is diffused through an angle up to the associated Brewster angle of the fibers. This angle is greater than 60° resulting in a minimum viewing cone of acceptance of 120°.

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A second implementation utilizes a CRT projection system employing a phosphor screen as a backlight. This screen has the property that it absorbs part of the incident radiant energy, converting it to a diffuse point light source, while specularly transmitting the remaining portion. The longer wavelength diffuse component backlights the imagery while the specular component, modulated by the film density, is sensed by the area detector. The frequency of the diffuse component, determined by the characteristics of the phosphor used in the screen, will be below the cut-off frequency of the detector. Thus the detector will sense only the high-resolution specular component while passing the lower frequency diffuse component.

The selection of a backlight phosphor can be determined primarily by the emission and absorption characteristics of the phosphor compatible with the available incident radiation and color requirements of the backlight. Varying the concentration of the phosphor in the transparent substrate will permit latitude in the selection of the transmitted to absorbed ratio of the incident radiation. Many phosphors are available which satisfy these requirements and can be used in the backlight system.

A phosphor screen consisting of Fluorescein impregnated Plexiglas was fabricated and tested on the experimental breadboard. The resulting backlight was diffused while the plate passed a portion of the incident radiation specularly. A high percentage of diffuse radiation produced in the phosphor plate is trapped by internal re-

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flection within the plate. This percentage is reduced by producing a diffuse surface on the side of the phosphor plate nearest the film. This process would reduce internal reflection on one surface reducing the optical trapping effect. The sensing component is also diffused at this surface, but the physical contact of the film and diffused surface would maintain the resolution of the sensing spot.

Further work is required in this area in an effort to increase the efficiency of this backlight technique and is recommended in the follow-on program.

E. CLOSED-LOOP STUDIES

1. General

The closed-loop studies concentrated in two major areas. The first area of investigation was the examination of various phosphors which were suitable for use in cathode-ray tubes employed as a modulated backlight. The second area of investigation consisted of the development and breadboarding of optical and feedback configurations compatible with the system requirements for each type of phosphor. Each of the CRT's containing the phosphors to be investigated was scanned in the same manner. A standard 525-line, 15750 cycle horizontal scan frequency, 30-cycle frame rate was employed. Slower frame rates for real-time feedback and modulation were determined to be undesirable due to flicker or uneven light distribution across the face of the CRT when using long persistence phosphors. Each of the breadboard systems utilizing the selected phosphors and various sensors

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incorporated into each optical and feedback implementation was fabricated for closed-loop operation. Results of the study of each configuration are described herein.

2. Phosphor Investigation

The desirable characteristic of a phosphor used in a modulated backlight CRT are:

(1) high light output,
(2) good dynamic range,
(3) fast decay for good resolution,
(4) white light.

Five phosphors appeared to possess several of these desirable characteristics and were chosen for further investigation: P-4, P-17, P-16, P-15 and P-16 combined with P-4.

a. P-4 Phosphor. The P-4 phosphor is a compound phosphor which produces a white light source. The light output capability of the P-4 is compatible with the 2,000 ft-lambert brightness goal as is evidenced by its use in theater projection TV systems. The shortest decay time, 25 microseconds, is exhibited by the blue component of the sulphide type phosphor. While this long decay time seriously limits the feedback bandwidth capabilities of the modulation system it was felt that the other desirable characteristics of the phosphor warranted an implementation using P-4.

b. P-17 Phosphor. The P-17 phosphor produces a yellowish-green output, but contains a blue component which has a decay time of

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approximately 5 microseconds. The P-17 was investigated primarily to determine if the bandwidth problems associated with the P-4 could be effectively overcome.

c. P-16 Phosphor. The P-16 phosphor was investigated because of its extremely fast decay time of 0.12 microsecond. The P-16 produces an output in the blue-violet region. The light output capability of the P-16 is relatively low compared to the other phosphors investigated.

d. P-4 and P-16 Phosphors. A comparison of the characteristics of the P-4 and P-16 phosphors indicated that a combination of these phosphors into a single CRT should produce nearly all of the characteristics desirable for the modulated backlight. By substituting the P-16 phosphor for the blue component of the P-4 a combination phosphor should result which produces white light capable of high intensity with a blue component of fast decay for sensing. A CRT containing the compound P-4 and P-16 phosphor was purchased, however, this tube did not produce the desired characteristic. The light output was a yellowish-green color and the decay time of the blue component was greater than 1 microsecond. This poor performance has been attributed to either an insufficient deposit of the P-16 phosphor or a chemical recombination when the two phosphors were mixed. Although time did not permit, further investigation of this phosphor combination approach is certainly warranted.

e. P-15 Phosphor. Of all the phosphors investigated, the P-15

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was the most thoroughly tested. P-15 phosphor produces a greenish-white color that is capable of moderately high intensity. It contains an ultraviolet component that decays in 0.05 microsecond. The green component of the phosphor decays in approximately 2.8 microseconds. Tests on the P-15 phosphor were run using the ultraviolet component for sensing and feedback while viewing the green; and using the green for both sensing and viewing.

3. Breadboard Implementations

The basic configuration used to test the various phosphors and sensing elements consisted of a CRT for backlighting, a transparency, a sensing element or color separating device, a photomultiplier to convert the modulated light received into a video signal, and a negative feedback amplifier to deliver enough signal to intensity-modulate the CRT. Scanning of the CRT's was done at conventional TV rates and by using magnetic deflection. CRT's containing the slower phosphors such as P-4 and P-17 were conventional 14-inch television tubes. CRT's containing the higher speed P-15 and P-16 phosphors were high resolution 5-inch tubes. The photomultiplier used was an RCA Type 6199 with an S-11 photocathode. The breadboard implementation using the P-4 phosphor is shown in Figure 2.

The characteristics of the dichroic mirror are such that the blue component is reflected to the photomultiplier, while the remainder of the visible light passes through to the viewer. A bandwidth of 16 kilocycles was obtained using the blue component for

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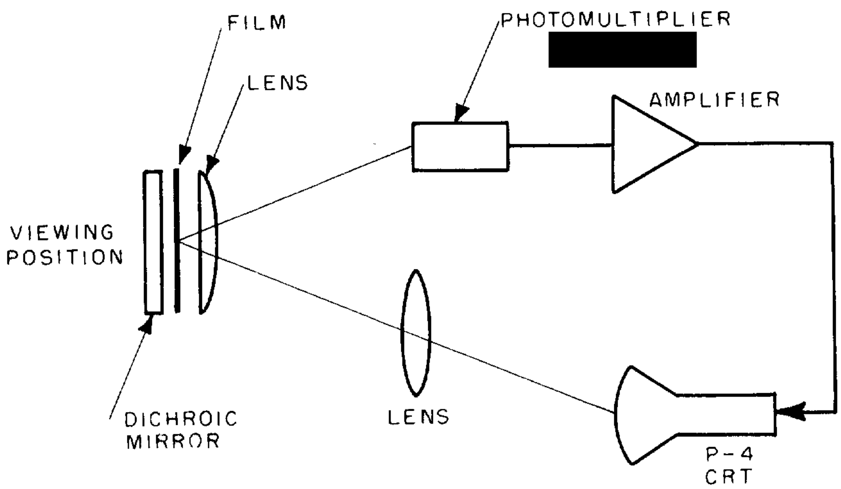

Figure 2. Breadboard Implementation with P-4 Phosphor

sensing. This was manifested as a large lag when viewing the resultant modulated output and was determined to be unacceptable.

The P-17 phosphor was also tested with the preceding implementation. As was expected the system bandwidth was increased to approximately 300 kc although some lag in the modulation was still observed using the dichroic mirror implementation. The yellow-green color of the P-17 was also judged to be undesirable.

An attempt was made to utilize the dichroic mirror configuration with the P-4/P-16 combination phosphor. However, the light reaching the phototube was of too low a level to produce a reasonable video signal-to-noise ratio. This was caused by the initial low blue output from the P-16 component of the phosphor compounded by the effective squaring of the opacity of the transparency and the reflectivity of the film base and field lens.

At this time it was determined that a sensing element other than a dichroic mirror would be required to achieve an adequate signal-to-noise ratio (see Section 3-C). While a better sensing system was being developed, the direct system of Figure 3 was used to further investigate the P-4/P-16 combination.

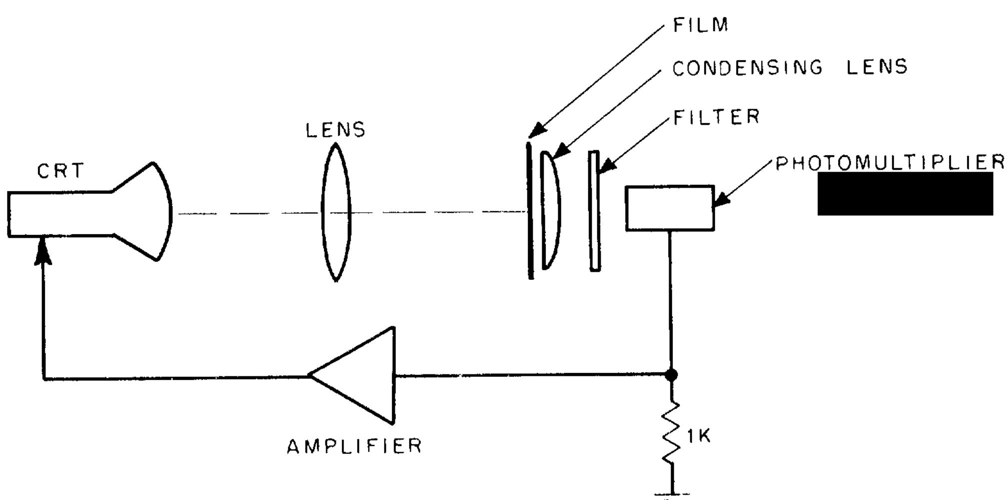

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Figure 3. Direct Sensing System

Removal of the dichroic mirror resulted in increased, although still poor, signal-to-noise ratio. By modulating the control grid of the CRT and monitoring the phototube output, data was gathered for the phosphor response curves shown on Figure 4. It can be seen that, with optimum filtering, the upper corner

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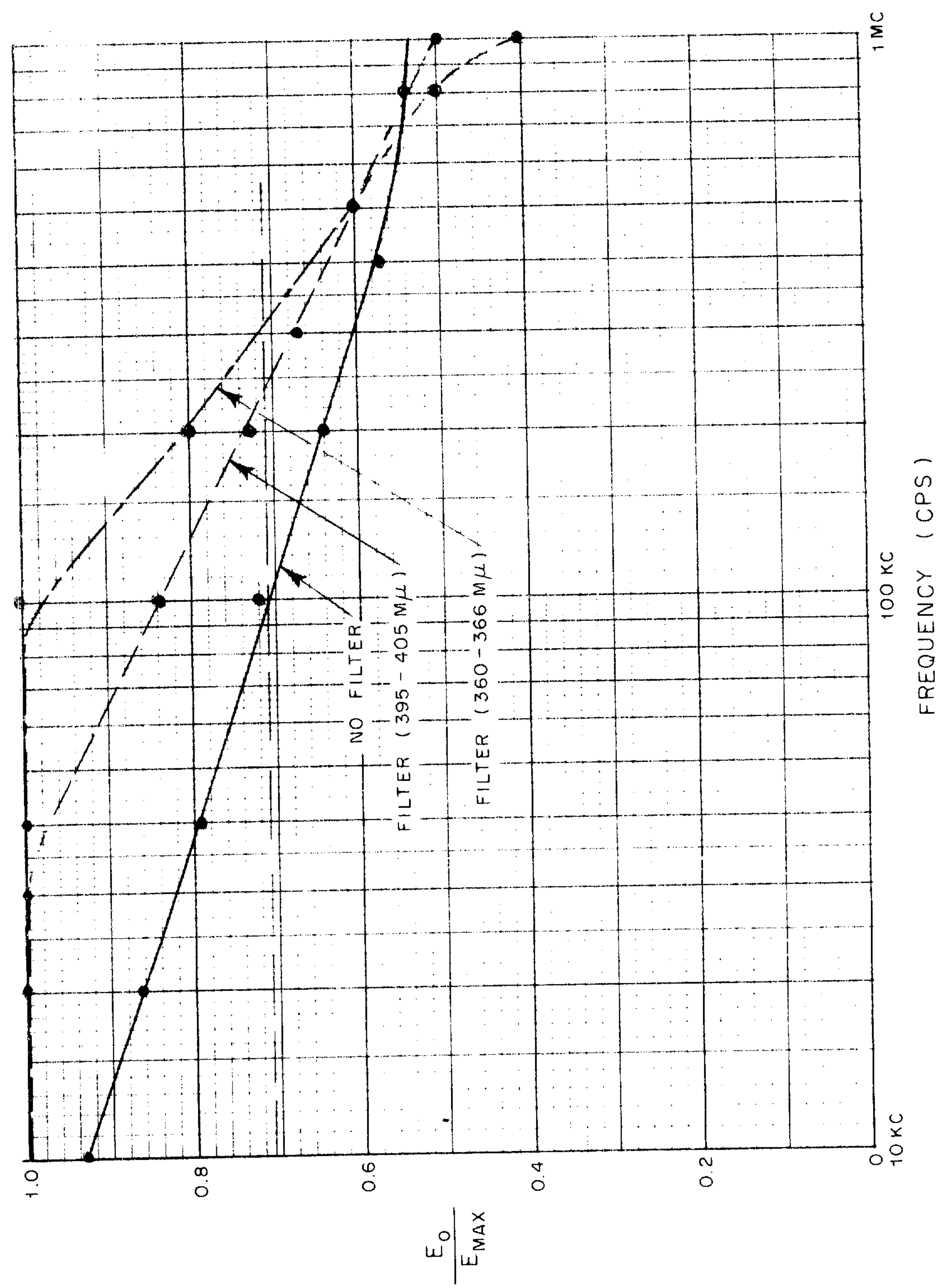

Figure 4. Phosphor Response of 14M18PM CRT

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frequency is slightly greater than 300 kc. The conclusions drawn for this particular tube are that:

(1) There is not enough P-16 deposited to emit sufficient light at the high frequencies to maintain a flat phosphor response. Even though the P-4 is greatly attenuated by the filter the ratio of concentration of P-4 to P-16 is so great that the filter output contains a sufficient amount of P-4 light to limit the frequency response.

(2) A possible chemical combination of the two phosphors has occurred which results in an entirely new phosphor characteristic.

Although time limited further investigation of this combination of phosphors approach it is felt that the advantages inherent in P-4 and P-16 combinations are sufficient to warrant further effort and is, therefore, recommended in the follow-on program.

With the development of a fluorescent sensing element the breadboard system was modified to that shown in Figure 5. Both P-15 and P-16 phosphor CRT's were used in the breadboard. The P-16 phosphor was discarded because of its inherently low light level output and blue-violet color. The bandwidth calculations which follow, however, apply equally to both phosphors.

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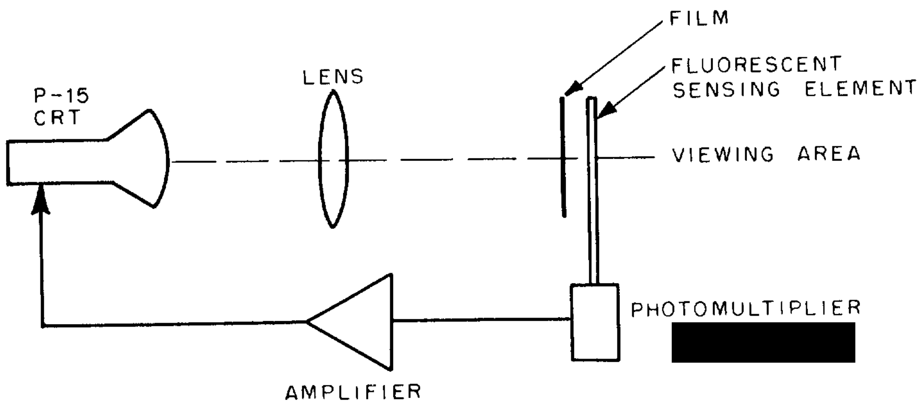

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Figure 5. Fluorescent Sensing System

A wide band, high-gain, rising-gain amplifier was developed for this loop. The rising-gain characteristic was an attempt at phosphor compensation to increase system bandwidth. The initial amplifier parameters are shown on Figure 6 - curve C and D.

The fluorescent sensing element was developed as a solution to the problem of direct viewing while detecting a signal proportional to film density. The modulated ultraviolet radiation is detected by a transparent plate photo detector placed over the film. The detector consists of a transparent plastic substrate such as Plexiglas impregnated with a luminescent material. The incident ultraviolet, modulated by the film density excites the luminescent material causing

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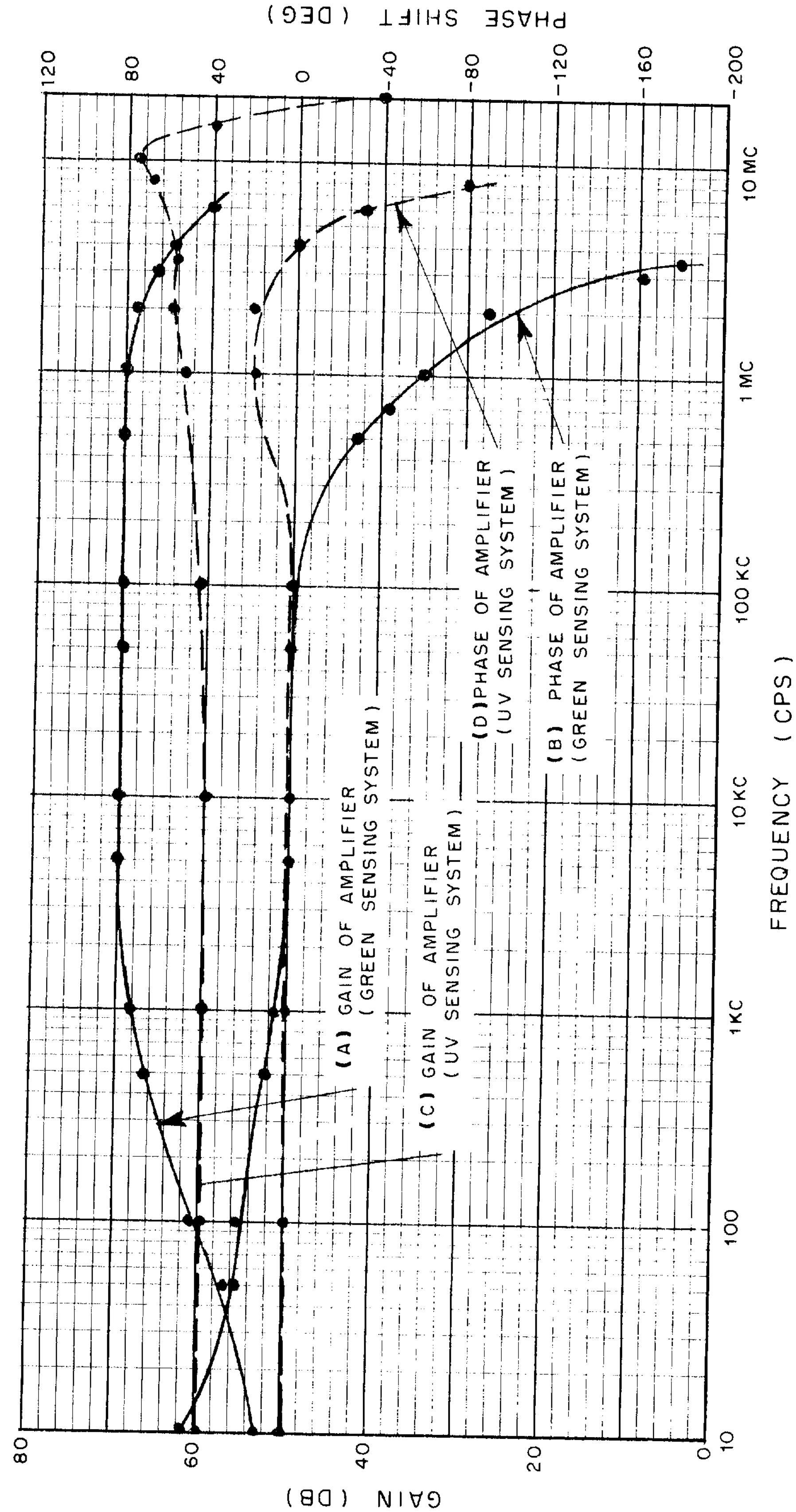

Figure 6. Initial Amplifier Parameters

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it to fluoresce. Most of the radiation is trapped within the Plexiglas plate and travels by internal reflection to the photomultiplier placed at one edge of the plate. The photomultiplier then converts the light signal to an electronic signal. The necessary conditions the plate must meet are that it be large enough to cover the film, transparent, colorless, be excited by the ultraviolet component of P-15 phosphor, and produce a radiation spectrum that is optimum for visual response and adequate for photomultiplier detection. The development of the sensing element is discussed in Section 3-C.

The P-15 phosphor offers the advantages of a ultraviolet component that can be used for sensing and a greenish-white component for backlighting. The ultraviolet sensing of the P-15 allows the phosphor limitation of the system to be extended to approximately 6 mc as determined by the Sine-Wave Response curve (Figure 7). The phase angle, which is also plotted, provides the phase information required to calculate the parameters of the feedback amplifier.

To establish the gain required in the feedback loop, the minimum detectable signal output of the photomultiplier and the voltage swing required at the grid of the CRT were measured. The minimum detectable signal was measured to be 30 mv with a S/N of 10 to 1.

Referring to Figure 8, Photomultiplier Output vs. Grid No. 1 Voltage (Ultraviolet Sensing), it is noted that for linear operation on the curve the grid voltage variation is from -70 volts to

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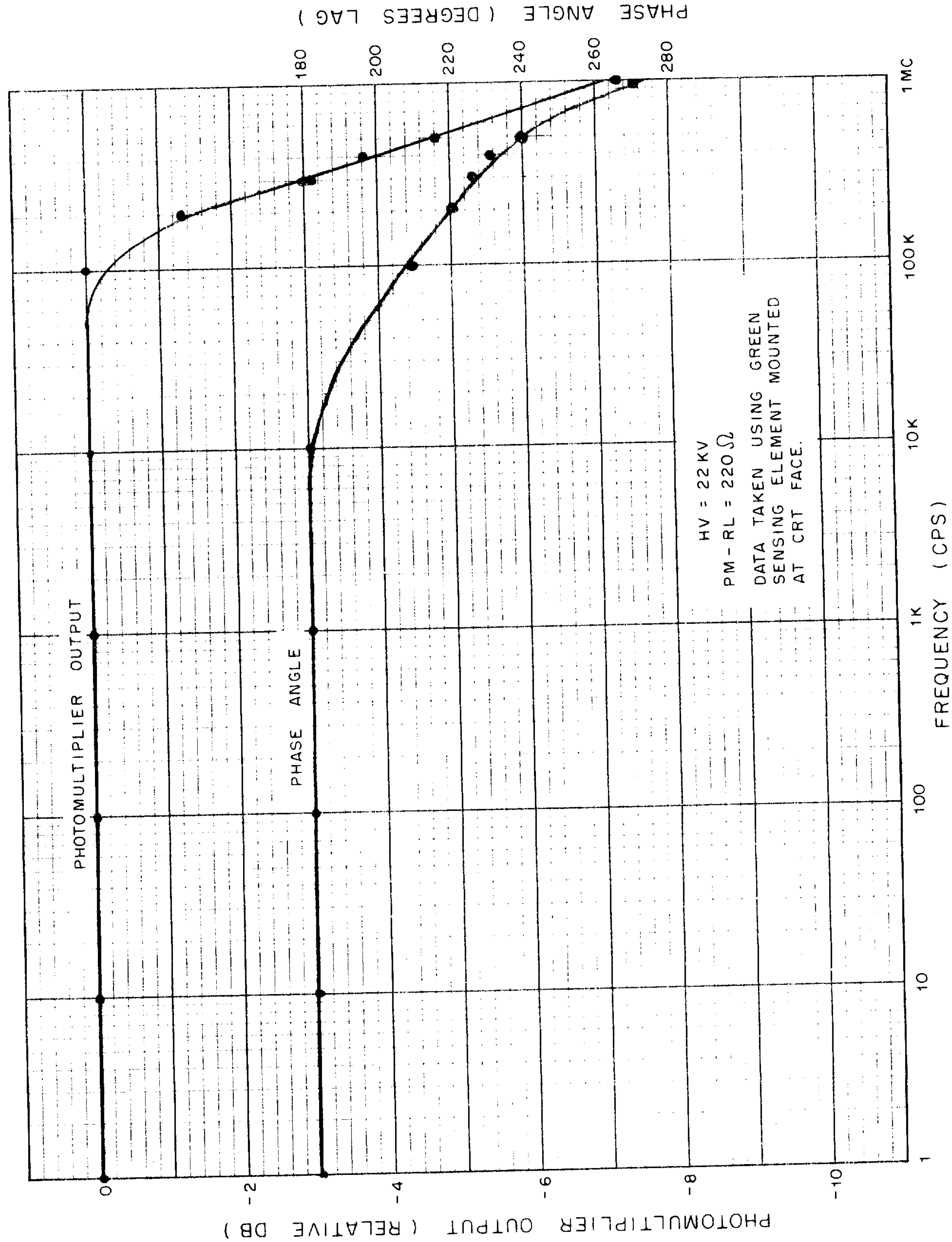

Figure 7. Ultraviolet Sine-Wave Response

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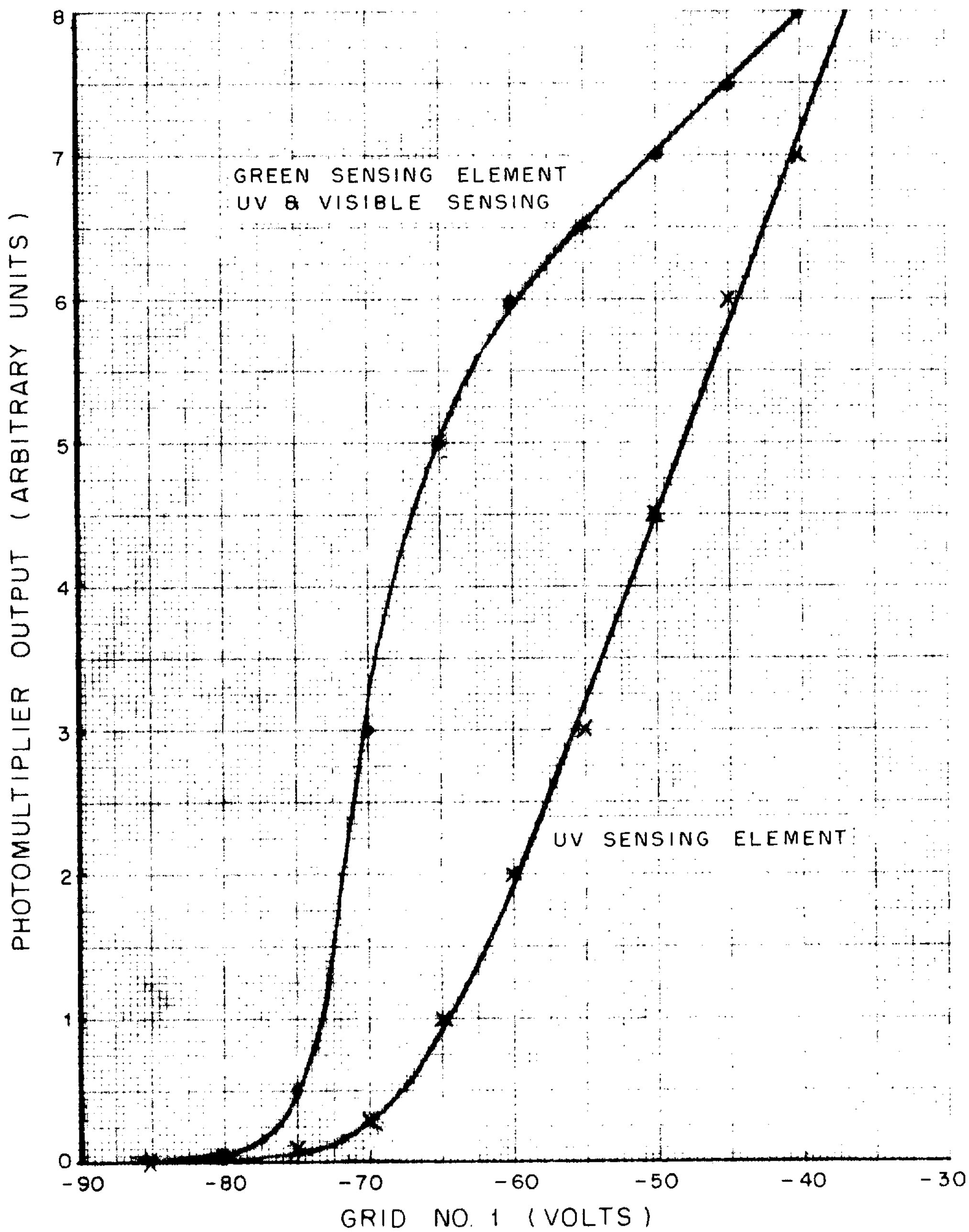

Figure 8. Photomultiplier Output vs Grid No. 1 Voltage

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-40 volts. This voltage variation of 30 volts is the required output of the feedback amplifier.

Using the preceding information, the parameters of the amplifier were set at: Gain = 30 volts/30 mv = 1000, BW $\geqq$ 8 MC, and phase angle to vary in conjunction with the phosphor phase angle for a phase shift of less than 180°. The characteristics of this amplifier are shown in Figure 6 - Curves C and D.

Operation of the system is limited in dynamic range by the light output as shown on the Visible Light Output vs. Grid No. 1 curve - Figure 9. The minimum light level that can be obtained while still operating on the linear portion of the Photomultiplier Output vs Grid No. 1 curve (Ultraviolet Sensing) - Figure 8 is 50 ft-lamberts. This allows a visible light dynamic range from 50 ft-lamberts to 190 ft-lamberts. Operation into the lower light levels is limited because of the rapid decrease of ultraviolet at these levels. In an effort to optimize operation, the minimum light level was decreased to 20 ft-lamberts - extending operation into the non-linear region of the curve. However, this dynamic range of 20 to 190 ft-lamberts was judged to be insufficient.

To increase the dynamic range of the light output, sensing of both the visible and ultraviolet light output was initiated. This approach offers a sensing system with less bandwidth; however, it offers a greater dynamic range in light output. Using a sensing element which responds to both the visible and ultraviolet a 10 mv

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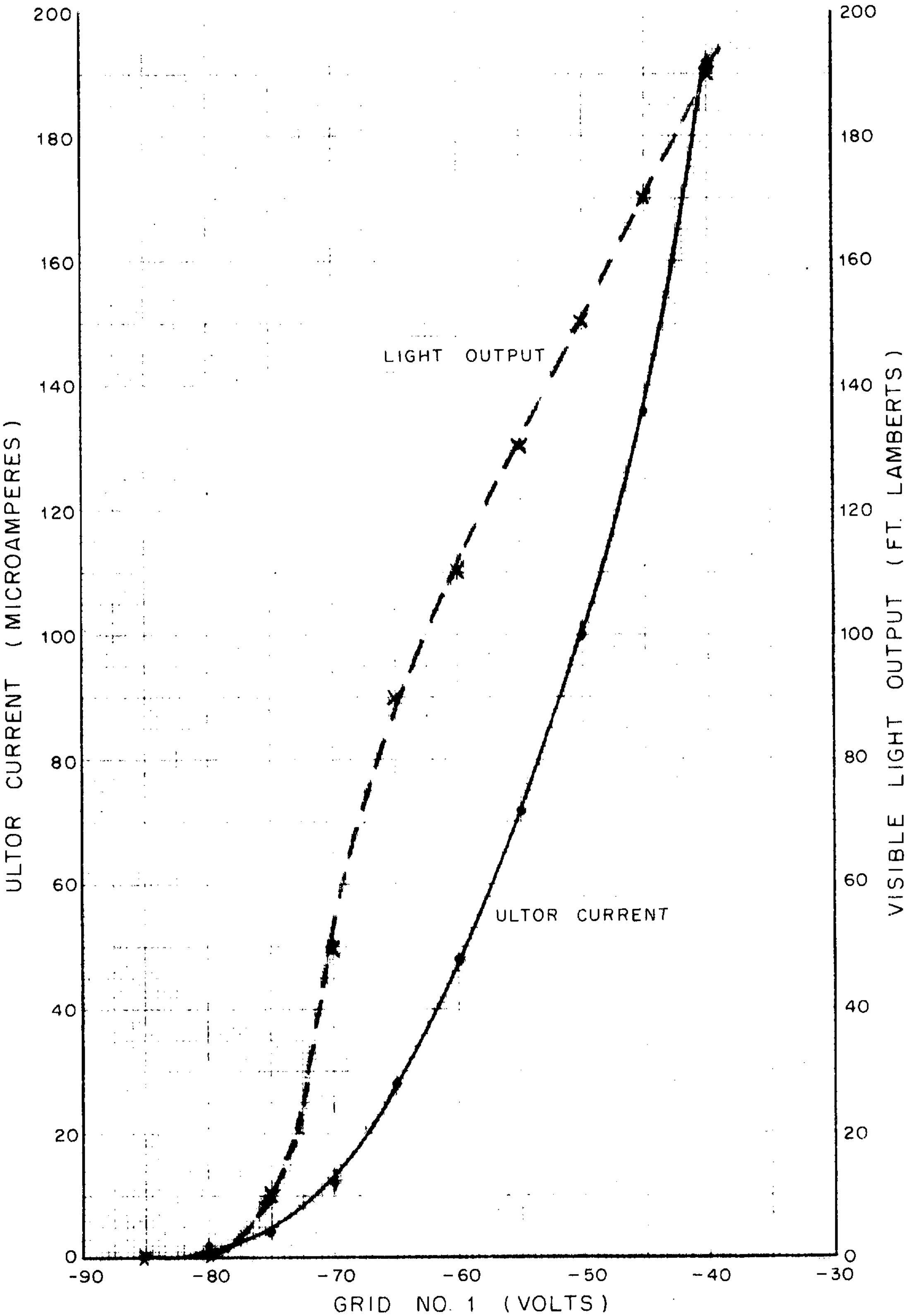

Figure 9. CRT Characteristics

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minimum detectable signal for a S/N of 10 and a minimum light level of 3 to 5 ft-lamberts was detected at the photomultiplier.

From the curve shown in Figure 8 relating the visible and ultraviolet sensing photomultiplier output to grid voltage, it is noted that a usable output exists down to approximately -77 volts on the grid. Referring to Figure 9, this represents a light output of about 3 ft-lamberts.

Since the sensing utilizes both the visible and ultraviolet, the sine-wave curves shown in Figure 10, combined with the minimum detectable signal and required modulating voltage, set the new parameters which are required in the amplifier. (Gain = 30 volts/10 mv = 3000 and BW $\geqq$ 1 mc.) The characteristics of the amplifier used for visible and ultraviolet detection are shown in Figure 6 - curves A and B.

Using the visible and ultraviolet for sensing results in greater contrast as compared to the ultraviolet sensing only; 190 ft-lamberts/3 ft-lamberts or 63/1 for visible and ultraviolet, compared to 190 ft-lamberts/20 ft-lamberts or 9.5/1 for ultraviolet only. However, using the visible and ultraviolet for sensing, limits the resolution because of the slow visible phosphor response.

Operation of the breadboard system as shown in Figure 5 presented limitations in actual viewing because of viewing into the lens aperture. To eliminate this limitation, the lens was removed as shown in Figure 11. This also results in a decreased gain require-

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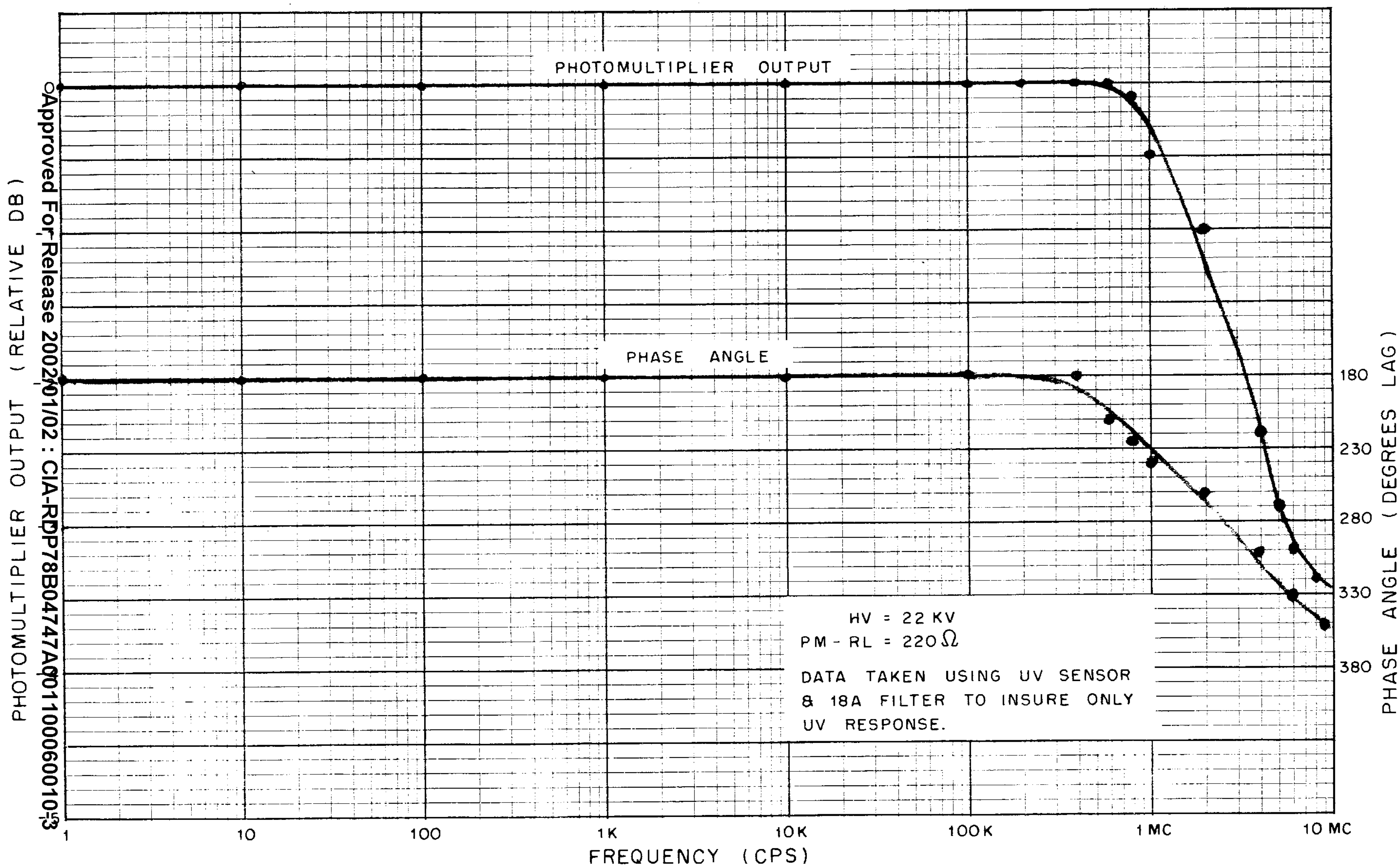

Figure 10. Combined Visible and Ultraviolet Sine-Wave Response

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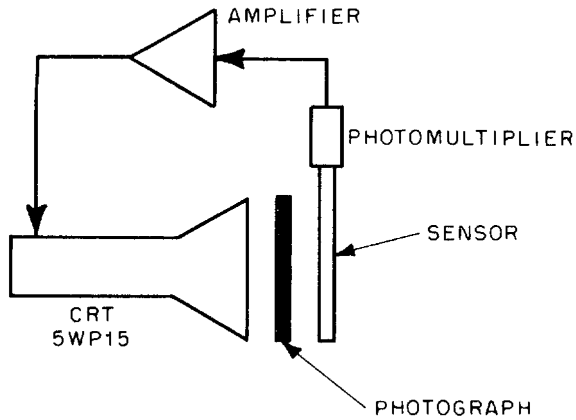

Figure 11. Lenseless Configuration

ment for the amplifier. Operation as shown in Figure 11 creates a focus problem which can be resolved with a fiber optic faceplate - this is explained further in Section 3-F of this report. However, for purposes of defining the contrast capabilities of the system, the system shown in Figure 11 is adequate.

To determine spot size a system was set-up as shown in Figure 12 and the results were plotted as illustrated in Figure 13.

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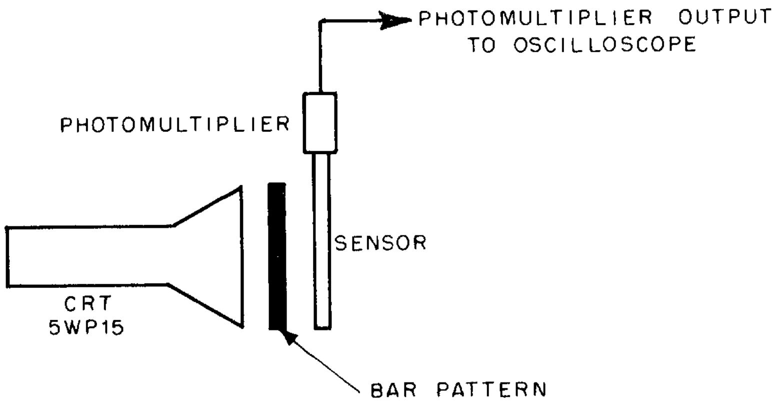

Figure 12. System to Detect Spot Size

Using the system shown in Figure 12, a bar pattern was scanned by the CRT and the output of the photomultiplier was monitored with an oscilloscope. Figure 14 shows the raster and the bar pattern that was scanned along with the video output of the photomultiplier as presented on the oscilloscope.

Using the information obtained from scanning the bar pattern and the curve shown in Figure 13, it is possible to determine the effective spot size. The curve shown in Figure 13 relates the percent modulation, α, and δ/λ, where δ is the width of the spot at the ϵ^{-1} amplitude of the gaussian curve, and λ, which represents

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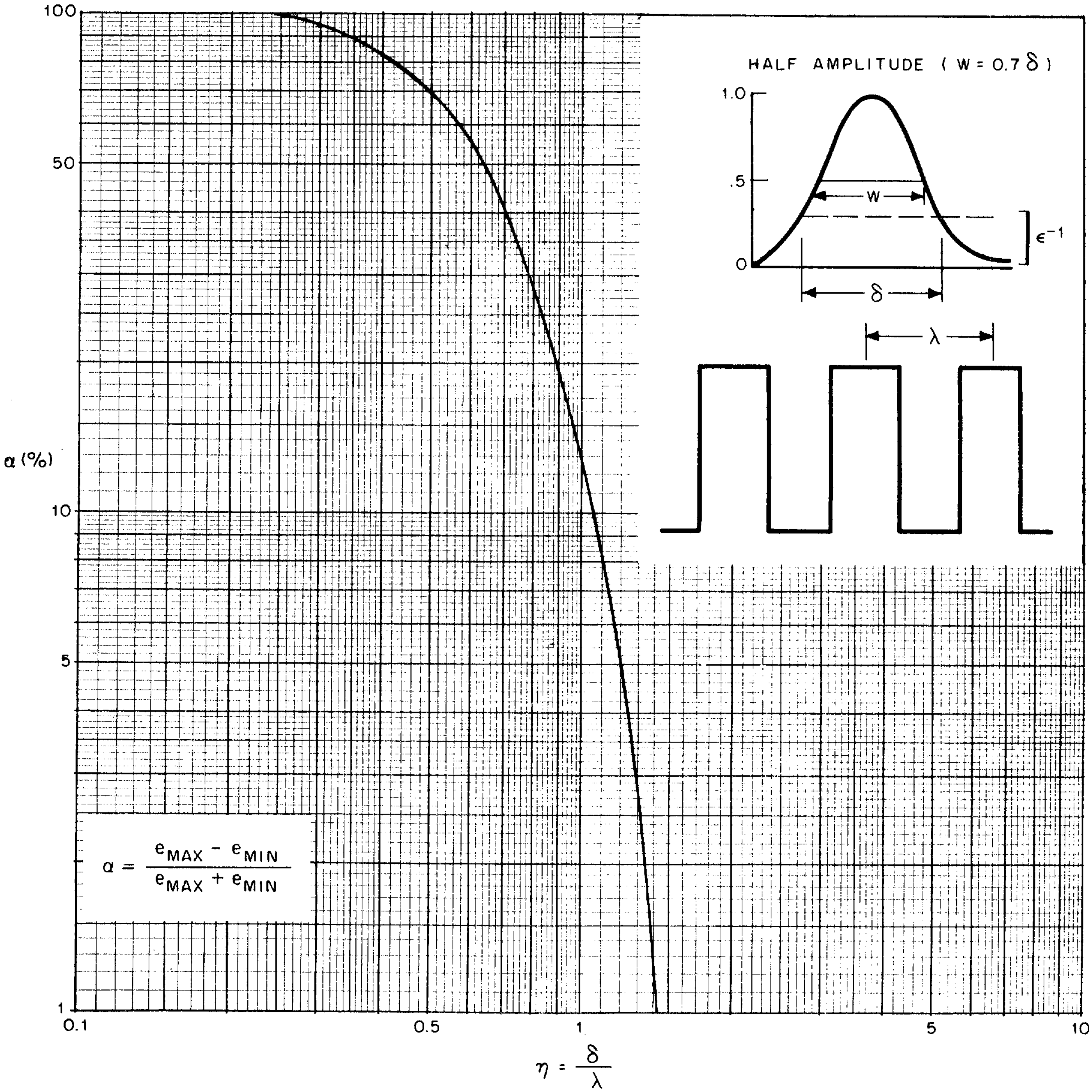

Figure 13. Square-Wave Response for Gaussian Aperture

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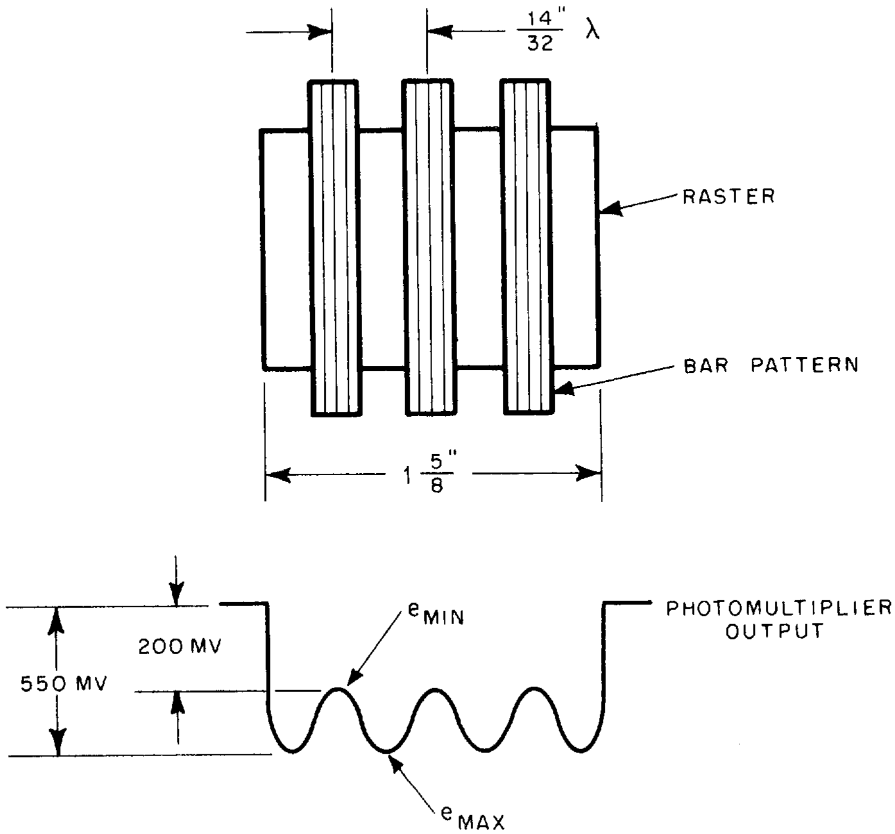

Figure 14. CRT Raster, Bar Pattern, and Photomultiplier Output

the pitch of the bar pattern. Also noted in Figure 13 is the relationship between α, e_{max} and e_{min}. Using this relationship and the data recorded in Figure 14

$$\alpha = \frac{e_{max} - e_{min}}{e_{max} + e_{min}} \cdot 100$$

$$= \frac{550 - 200}{550 + 200} \cdot 100 = \frac{350}{750} \cdot 100$$

$$\alpha = 46.5$$

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This number, 46.5, represents the percent modulation that occurred from scanning the bar pattern shown in Figure 14.

Using 46.5 for α and relating this to δ/λ on the curve shown in Figure 13 yields a δ/λ of 0.61. Solving this for δ, where λ = 14/32-inch, gives

$$\delta = (0.61)\ (\lambda)$$

$$= (0.61)\ (14/32\text{-in})$$

$$\delta = 0.266 \text{ in.}$$

Relating to the gaussian curve shown in Figure 13, it can be shown that $W = 0.7\delta$, which is the spot width measured at the half-amplitude points. From this, the spot size is given by

$$W = 0.7\delta$$

$$= 0.7\ (0.266)$$

$$W = 0.186 \text{ in.}$$

This spot size, 0.186 inches, represents the effective spot size for the system shown in Figure 12 and can be used in determining the resolution of the system. It can be shown that a 5 percent modulation occurs when the spots are displaced a distance equivalent to the half-amplitude width of the spot.

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For a 9-inch by 9-inch raster, the maximum resolution available in the horizontal direction would be

$$R_H(MAX) = \frac{9\text{-in}}{0.186\text{-in}} = 49 \text{ elements}$$

The photographs shown in Figures 15, 16 and 17 illustrate various amplitudes of CRT modulation utilizing the system shown in Figure 11. The conditions of operation are shown with the corresponding photograph.

NOTE

Following each illustration (Figures 15, 16, and 17) are glossy photographs. These photographs provide evidence of the quality of resolution obtained.

Figure 15A represents an unmodulated CRT operating at an ultor current of 40 μamperes and light output of 40 ft-lamberts. Figure 15B is the modulated CRT with the gain of the system optimized. Note that the level of the background of the photograph remains constant while the bright areas are darkened to facilitate observation of the photograph. Figures 15C and D are conditions with less loop feedback. Note the corresponding decrease in contrast between dark and bright areas from Figures B through D.

Figures 16 and 17 illustrate the same capability as Figure 15

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except the initial (unmodulated) condition was altered. Figures 15B through D represent a corresponding decrease in CRT modulation (decrease of loop gain).

Photographs of the breadboard set-up of the Light-Modulated Film Viewing System (see Figure 11) are shown in Figure 18. Figure 18A shows the entire system: CRT, light sensor, photomultiplier, power supplies, amplifier and CRT deflection circuitry. The CRT, sensing element, and photomultiplier are also shown in Figure 18B. Figure 18C illustrates the electronics used for generating the raster, sweep waveform generators, unblanking waveform generator, yoke-driver power supplies, and vertical and horizontal yoke drivers. The amplifier is pictured in Figure 18D.

F. IMPLEMENTATION STUDIES

1. General

Utilizing the results of the preceding studies, various viewing system implementations were studied. These implementations are discussed below. All of these implementations permit the direct viewing of film and utilize the fluorescent detector developed on this program and described in Section 3-C. In addition, all implementations utilize a CRT which serves as the light table.

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2. P-15 CRT Implementation

This implementation utilizes a 14-inch CRT with a P-15 phosphor as a backlight. The face of the CRT serves as the light table as shown in Figure 19. Located above the CRT is the fluorescent

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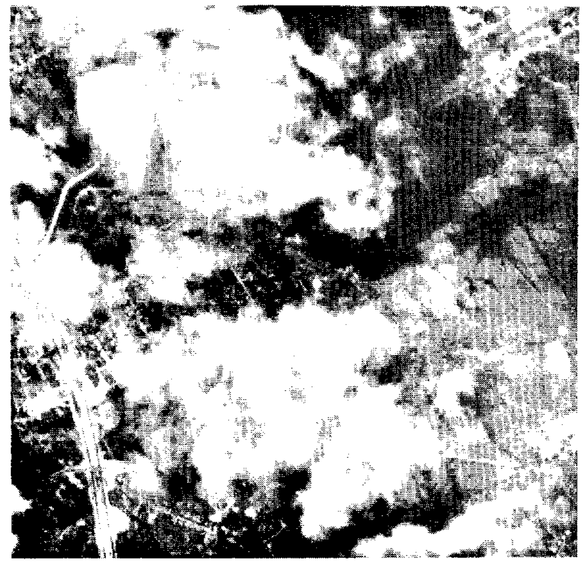
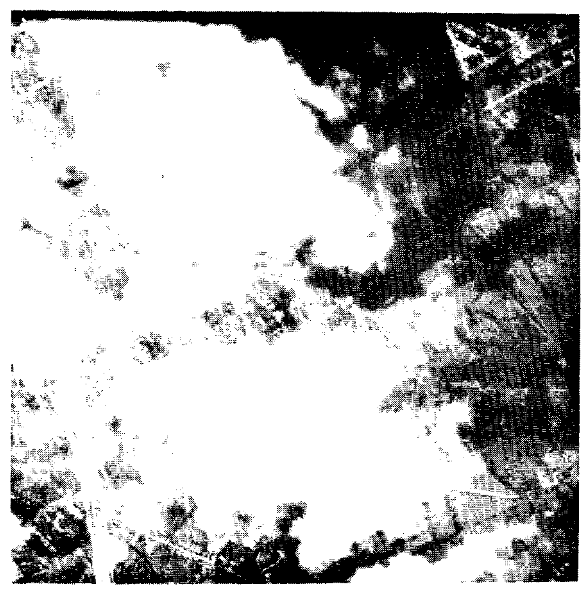
A. UNMODULATED CRT
ULTOR CURRENT = 40 μA



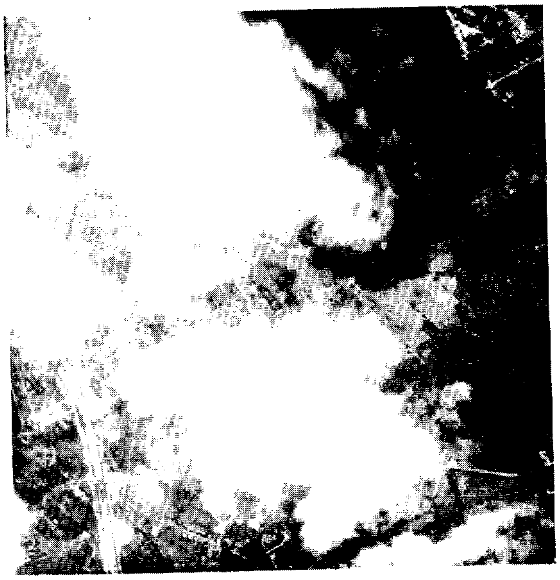
B. MODULATED CRT
AMPLIFIER GAIN = +41 DB

C. MODULATED CRT
AMPLIFIER GAIN = +34 DB

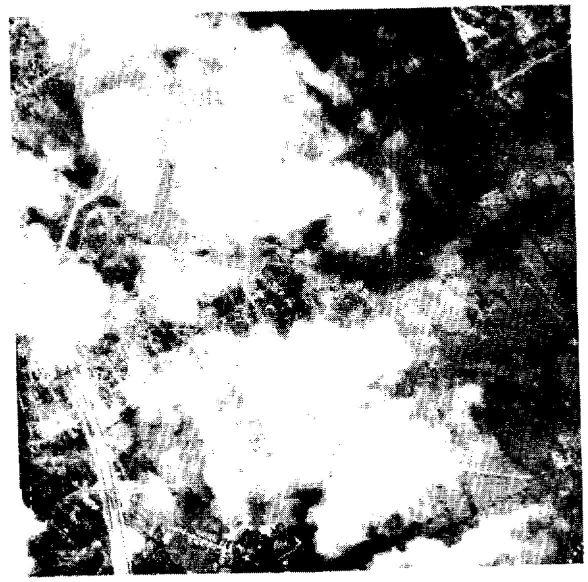


D. MODULATED CRT
AMPLIFIER GAIN = +30 DB

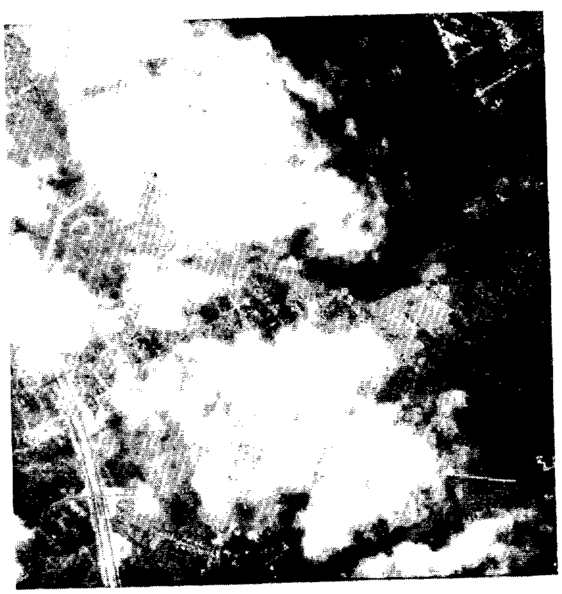
Figure 15. View of Aerial Scene with Initial Light Output of 40 Ft-Lamberts



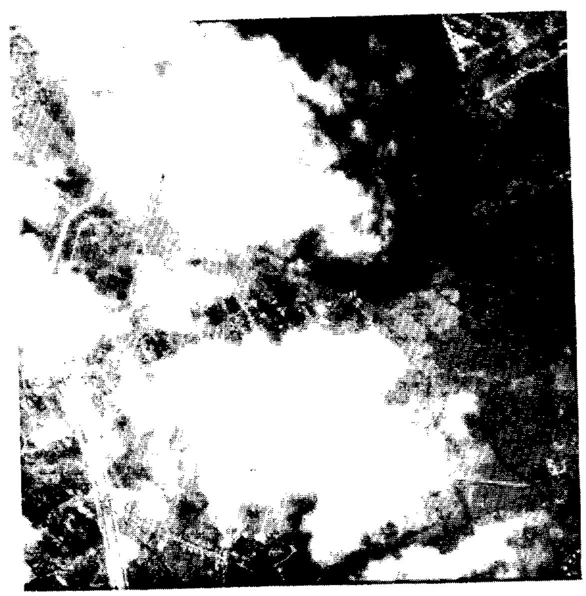
A. UNMODULATED CRT
ULTOR CURRENT = 28 μA



B. MODULATED CRT
AMPLIFIER GAIN = +39 DB

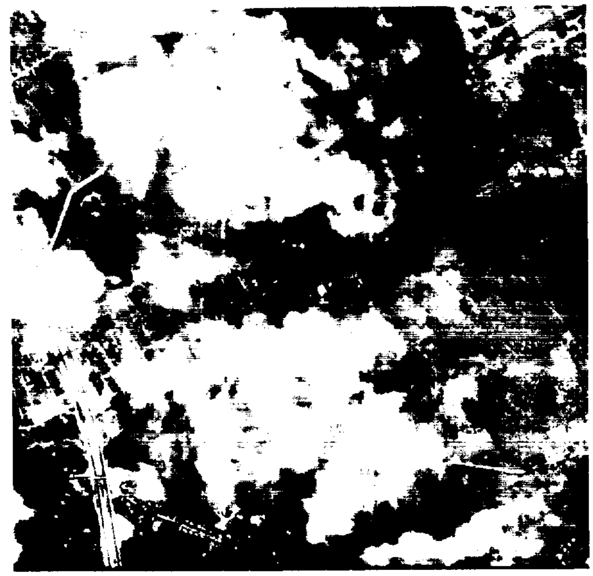


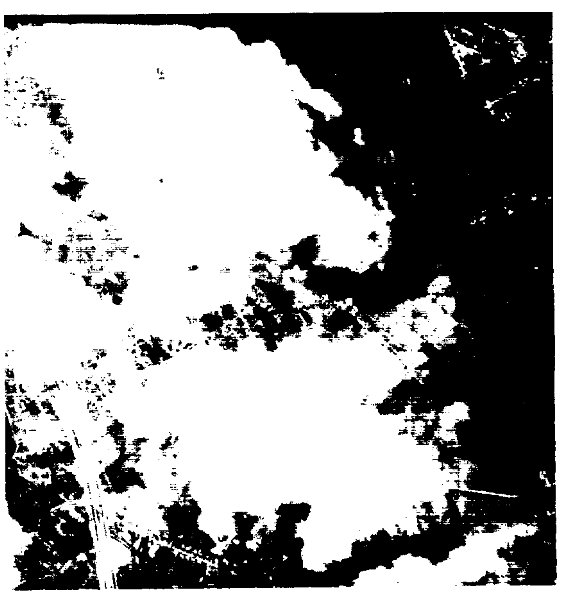
C. MODULATED CRT
AMPLIFIER GAIN = +31 DB

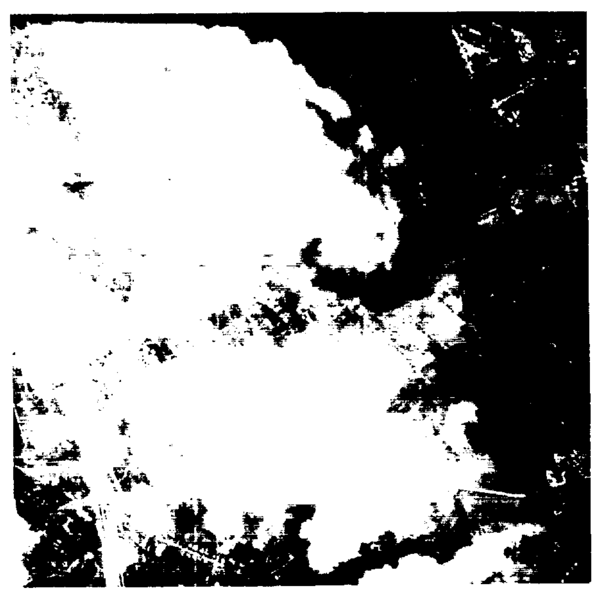


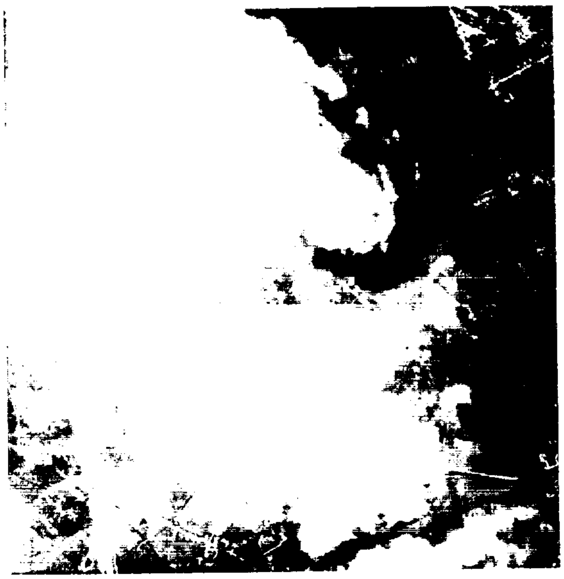
D. MODULATED CRT
AMPLIFIER GAIN = +26 DB

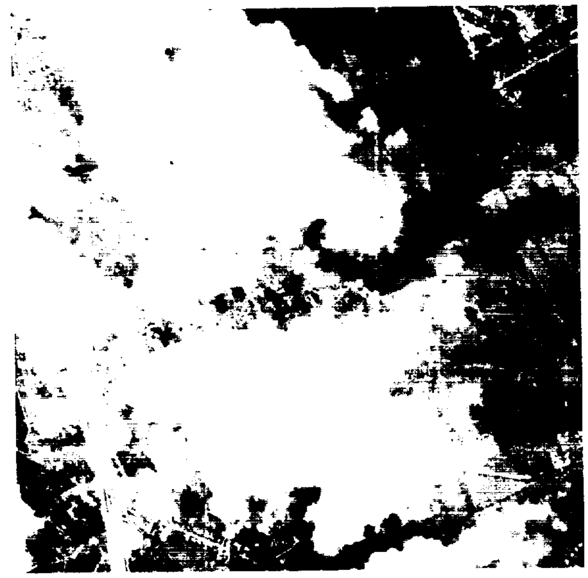
Figure 16. View of Aerial Scene with Initial Light Output of 28 Ft-Lamberts

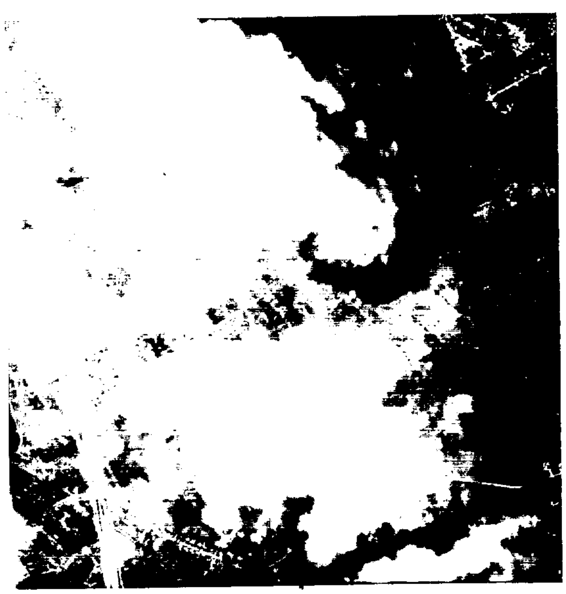


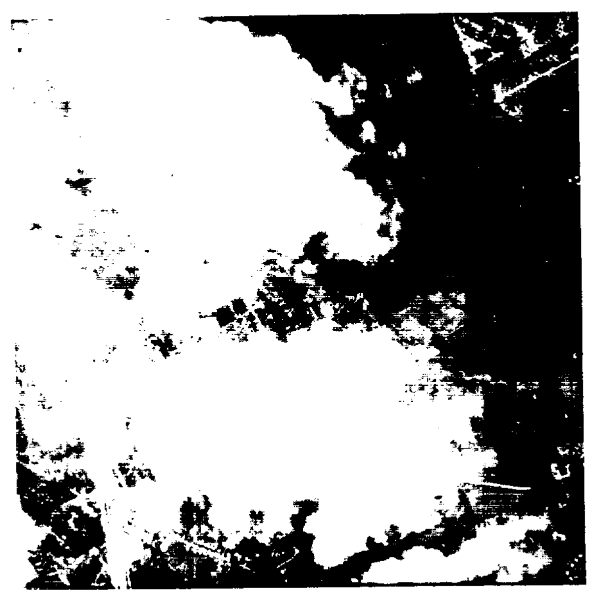


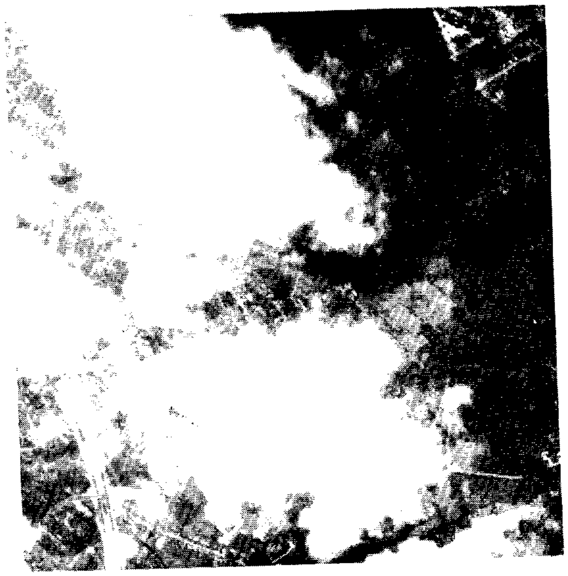




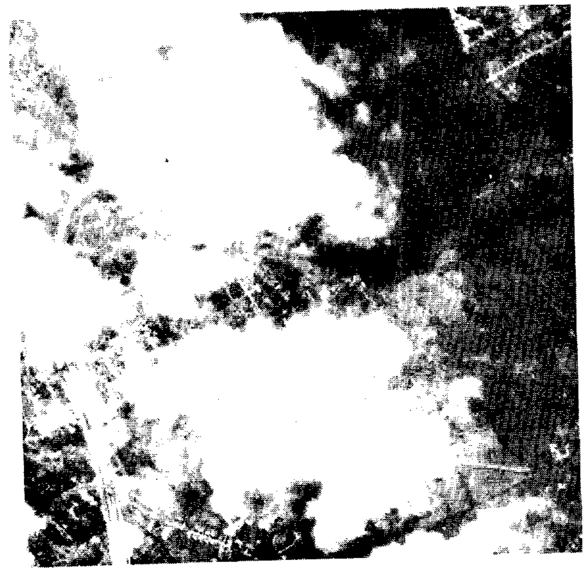




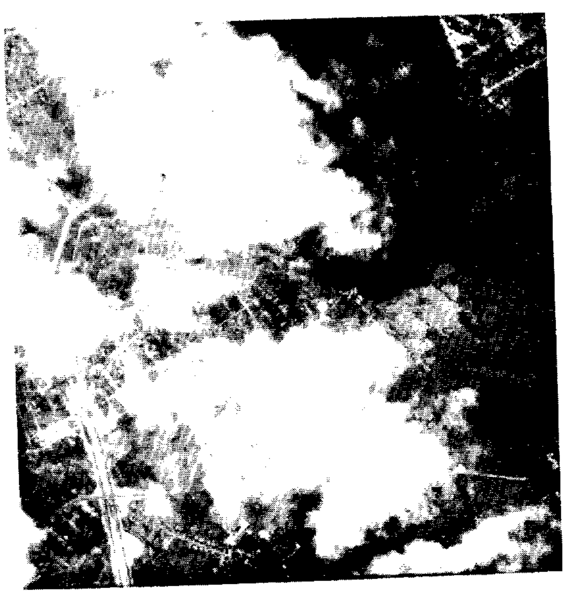




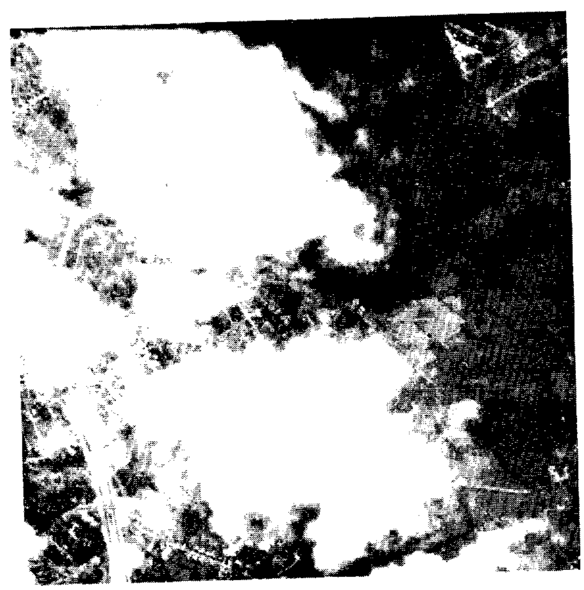
A. UNMODULATED CRT
ULTOR CURRENT = 16 μA



B. MODULATED CRT
AMPLIFIER GAIN = +33 DB

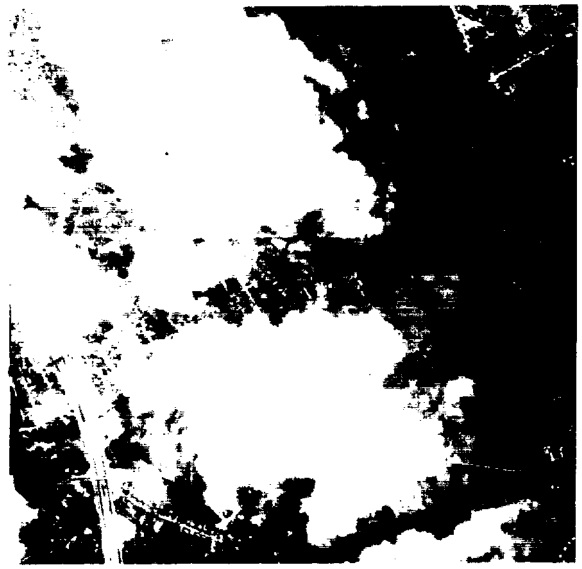


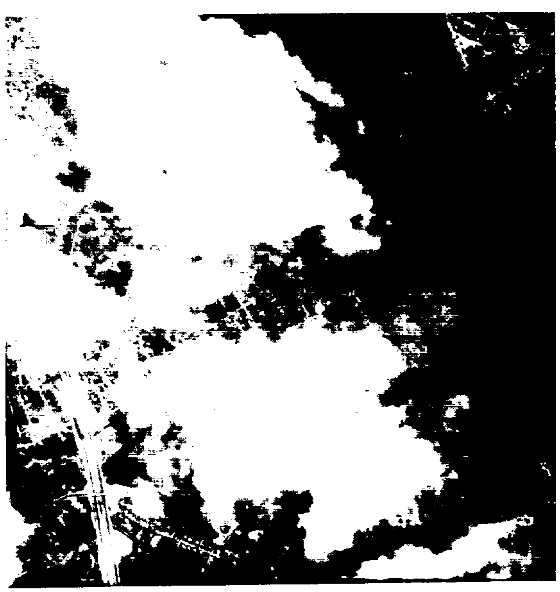
C. MODULATED CRT
AMPLIFIER GAIN = +26 DB

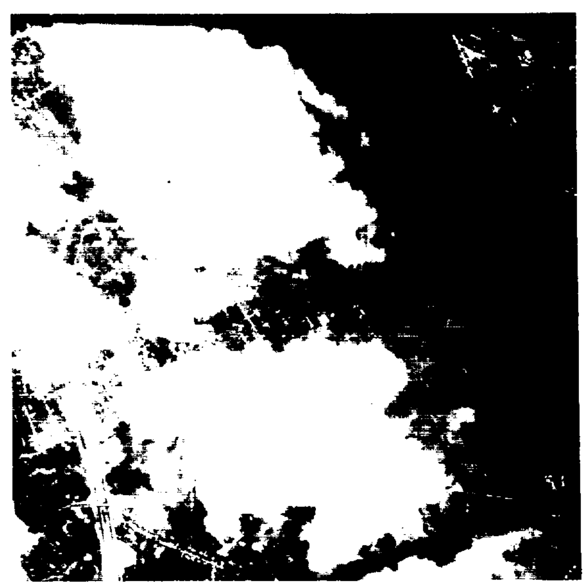


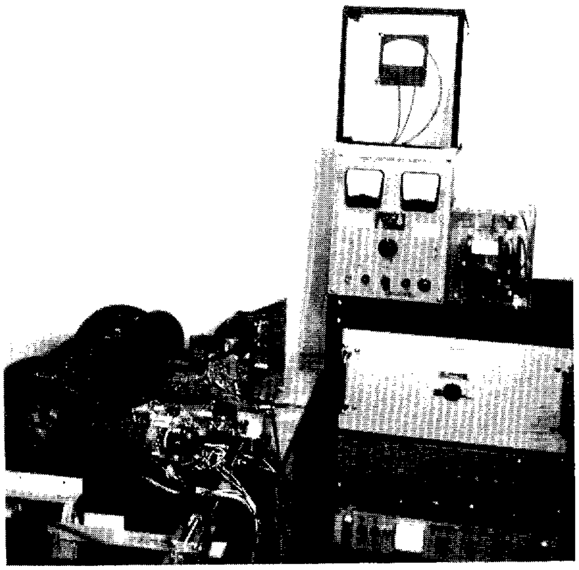
D. MODULATED CRT
AMPLIFIER GAIN = +20 DB

Figure 17. View of Aerial Scene with Initial Light Output of 16 Ft-Lamberts

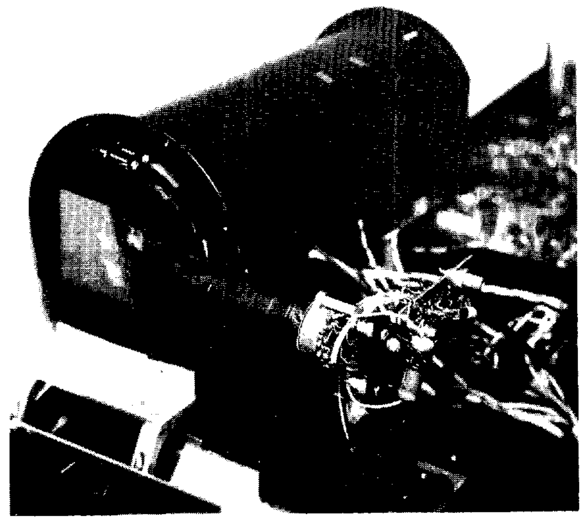




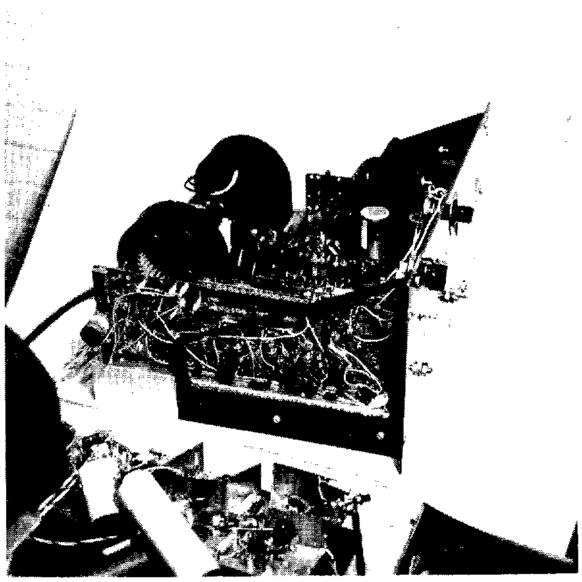




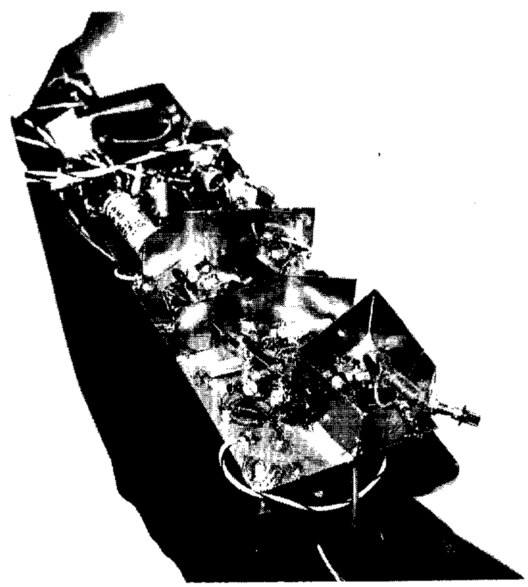
A



B



C



D

Figure 18. Breadboard Light-Modulated Film Viewing System Components

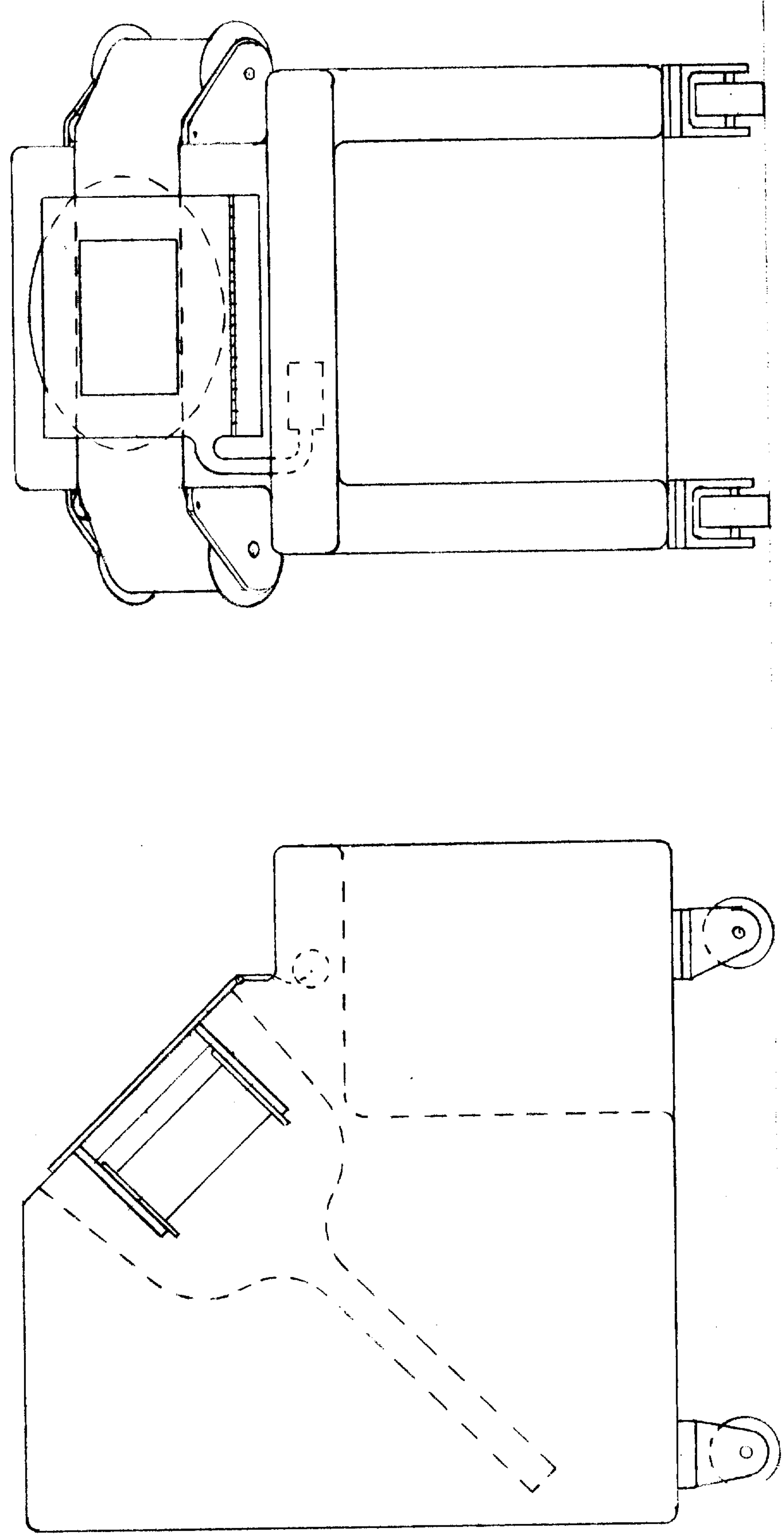


Figure 19. Viewer Console

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detector. Fiber optics are located around the edge of the detector which pipe the light to the photomultiplier located under the table. The detector, since it is made of Plexiglas and covers the complete faceplate, serves as a protective shield. In loading the film, it is slipped between the faceplate and the detector. The CRT in this implementation has a solid glass faceplate. If the thickness of the glass is 1/4-inch - the effective spot size will be about 186 mils - the same as that measured for the same thickness faceplate that was described in Section 3-E. With a 14-inch faceplate, it may be necessary to increase the faceplate thickness to about 0.34 inches, the effective spot size being about 252 mils.

When discussing the dodging resolution, it is desirable to consider the system made up of several apertures in cascade. Then the width of the overall aperture is

$$W_T = \left[\sum W_i^{\,2} \right]^{1/2}$$

The aperture due to spot size is a constant and equal to 0.186 inches. The aperture due to video bandwidth is

$$W_{BW} = \frac{.312D}{BW\ \tau}$$

where:

D = size of raster

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BW = video bandwidth (cps)

τ = horizontal sweep time.

It can be seen that the aperture caused by the video bandwidth can be reduced by (1) reducing the raster size, or (2) increasing the sweep time. The latter can be accomplished by reducing the number of vertical lines. In this manner, a better balance of vertical and horizontal resolution could be obtained.

With a P-15 phosphor, the video bandwidth is about 300 kc. This results in a resolution of

$$\tau = \frac{.312}{.300} = 1.04 \ \mu\text{sec}$$

Assuming a 1/4-inch faceplate thickness and a normal TV horizontal sweep time of 53 µsec, the dodging resolution due to phosphor decay is about 51 elements. The number of resolvable elements due to a 186 mil spot size when scanning a distance of 9 inches is 49. The resultant number of horizontal resolvable elements is 35. The number of vertical resolvable elements is 49.

A trade-off between horizontal and vertical resolution due to video bandwidth can be optimized by setting the number of resolvable vertical elements N_V, equal to the number of resolvable horizontal elements N_H.

$$N_V = \frac{1}{\tau F}$$

$$N_H = \frac{\overline{BW} \ \tau}{.312}$$

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where:

τ = horizontal sweep time

F = vertical frame rate

$\overline{BW}$ = video bandwidth

$$\tau = \left[\frac{.312}{F\ \overline{BW}} \right]^{1/2} = \left[\frac{.312}{30(30kc)} \right]^{1/2} = 180\ \mu sec$$

Therefore:

$$N_H = N_V = \frac{\overline{BW}\ \tau}{.312} = 179$$

The total number of resolvable elements, in both the horizontal and vertical directions, for a 186 mil spot size and a 300 kc bandwidth would then be 47. The gain characteristic of the amplifier could be modified to increase the video bandwidth, and effectively permit the system bandwidth to be limited only by spot size.

3. Implementation Utilizing a P-15 CRT with Fiber Optics

In the previous implementation, the system resolution was limited by the effective spot size due to the diffusion through the solid glass faceplate. This implementation eliminates this problem through the use of a fiber optics faceplate. With such a faceplate, the effective spot size is the actual spot size of the CRT and can be as small as about .002 inch. With the exception of the faceplate,

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this implementation is quite similar to the one described previously.

Discussions with various CRT manufacturers have indicated that the largest fiber optics faceplate CRT is 12 inches. This eliminates the possibility of a 9-inch by 9-inch viewing area using fiber optics. In addition, the cost of large fiber optics faceplates is prohibitive (e.g., a 12-inch CRT with fiber optics costs over [redacted] Therefore, the fiber optics faceplate implementation is only feasible for systems designed for viewing 5-inch film and smaller. The resolution of this implementation will be considerably better than the previous implementation because of the smaller effective spot size at the film plane. Since the optimizing of resolution presented in the discussion of the previous implementation was independent of spot size, the same raster parameters can be used here (i.e., a horizontal sweep time of 186 μsec). Resolution due to spot size for 5-inch film is 2500 elements in each direction (6,500,000 total). The total horizontal and vertical resolution in this case would be 178; being limited by the video bandwidth. Assuming that video bandwidth could be increased by phosphor compensation, the resolution could also be increased.

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4. Implementation Utilizing a Multi-Gun CRT

For a high resolution detection system, the CRT phosphor should have a very short persistence. Unfortunately, short phosphors radiate in the ultraviolet region and are not suitable for viewing detection. The P-15 phosphor offered a possible solution since the ultraviolet portion is quite short (.05 μsec) and the greenish-white portion is considerably longer and a reasonable color for

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viewing. As discussed in Section 3-E, the characteristic curve (brightness vs grid voltage curve) for the ultraviolet component of this phosphor is considerably different than that for the greenish-white component. This prevented the use of the ultraviolet component for detection and the greenish-white portion for viewing. An approach to circumventing this problem is through the use of a multi-gun CRT.

Consider a conventional color CRT which has three guns and a common deflection system. If one of the three color dots had a phosphor such as the P-16 (ultraviolet with a decay time of .12 usec) and the other two spots were P-4 (white with a relatively long persistence), the P-16 could be used for detection and the P-4 could be used for viewing.

If the detector material was Super Calcofluor, only the ultraviolet light transmitted through the film would be detected. This detection signal would then be used to modulate the other two guns which would intensity modulate the P-4 phosphor in a closed-loop fashion. With this arrangement, the gun and beam used to excite the P-16 phosphor dots would not be modulated. With such an implementation, the bandwidth of the detection circuit would be about 2.5 megacycle which would result in a considerably higher dodging resolution than can be obtained with the P-15 closed-loop implementations described previously.

5. Implementation Utilizing a Storage Tube

As shown in Section 3-F, the effect of the system aperture

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due to the video bandwidth is a function of the horizontal sweep time. One method of increasing the sweep time is to reduce the frame rate; however, this causes a flicker problem. This implementation involves the slow scanning of the film and storing the modulation signal in an electronic storage tube. After a complete slow scan, the frame rate is increased to 30 frames per second and the storage tube is read out and the resultant signal used to modulate the CRT. This implementation not only improves the dodging resolution but also eliminates many of the closed-loop stability problems. Of course, the storage tube approach can only be utilized while the film is held stationary. If the film is moving, the system can operate in normal closed-loop fashion (without the storage tube) with lower resolution. This implementation appears feasible since lower resolution can be tolerated while the film is moving. This approach requires further investigation and is, therefore, suggested as a study area in the follow-on program.

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SECTION 4

RECOMMENDED FOLLOW-ON PROGRAM

A. GENERAL

This program has resulted in a practical design concept for a Light-Modulated Film Viewer. This viewer utilizes a P-15 CRT as a backlight as described in Section 3-F. The viewer will have about 2500 dodging elements and a dynamic range of over 60 to 1. In the recommended follow-on program, [redacted] proposes to deliver a viewer of this type that can be evaluated operationally by a panel of photo-interpreters. In addition, advanced techniques studies are proposed in order to improve the bandwidth, brightness and dynamic range of the modulation and to reduce the size of the dodging element at the image.

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B. FABRICATION OF PROTOTYPE MODEL

A prototype model of a Light-Modulated Film Viewer will be fabricated and delivered. This model will utilize a P-15 CRT with the faceplate serving as the surface of the light table. The configuration of this model will be as shown in Figure 19.

The detector plate will consist of a sheet of plastic impregnated with a fluorescent material and will be mounted slightly above the faceplate to allow for film insertion. Fiber optics bundles will be mounted at the edge of the faceplate which will pipe the light to a photomultiplier located within the viewer cabinet.

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The viewing area will be 9-inches by 9-inches. The dynamic range of the modulation will be about 60 to 1 and the resolution will be about 50 elements in each direction (2500 over the area). A servo-driven film drive unit similar to that used on the change detector will be controlled by a joystick on the control panel.

C. ADVANCED TECHNIQUES STUDIES

The advanced techniques studies will investigate techniques to improve the performance of the Light-Modulated Film Viewer. It is anticipated that some of these techniques will be developed early enough to incorporate in the prototype model.

One area requiring further investigation involves the compounding of a combination phosphor such as P-16/P-4. If the proper proportions can be achieved, the P-16 ultraviolet flash can be used for detection and the longer P-4, which is white, can be used for viewing. This task would consist of a survey of phosphors and the purchasing of several CRT's with various phosphor compounds from a tube manufacturer such as [redacted] These tubes would then be evaluated in the laboratory breadboard model of the viewer.

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A second area of investigation involves the further development of the multi-gun and storage tube implementations described in Section 3-F. These implementations could increase the dynamic range and resolution of the viewer.

A third area of investigation concerns the improvement of

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the effective spot size of the viewer. This will include a further study of the phosphor plate used as a backlight described in Section 3-D. If the efficiency of this phosphor plate can be increased, both the bandwidth and effective spot size of the system could be improved. Another approach to improving the effective spot size of the system consists of projecting the CRT spot onto a back-projected screen material which would serve as the light table. This would diffuse the spot and place it very near the film thus retaining a small effective spot. The investigation of this approach will include an analysis of the efficiency of the projection optics and availability of high intensity CRT's in order to have an adequate brightness at the film plane.

D. SCHEDULE

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The above described program can be performed in nine months. The cost of the prototype model will be approximately [redacted] while the advanced techniques studies will cost [redacted]

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